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Compatibility of Material and Electronic Equipment With Hydrogen Peroxide and Chlorine Dioxide Fumigation

ASSESSMENT AND EVALUATION REPORT

Office of Research and Development
National Homeland Security Research Center

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Disclaimer

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List of Acronyms and Abbreviations

Ag	silver
Al	aluminum
APPCD	Air Pollution Prevention and Control Division
AVI	audio visual interleave
AWWA	American Water Works Association
BI(s)	biological indicator(s)
BIOS	basic input/output system
BIT	burn-in test
CBRTA	Chemical, Biological, and Radiological Technology Alliance
CD	compact disc
CD-ROM	Compact Disk - Read Only Memory
CD/DVD	compact disk/digital video disk
Cl_2	chlorine
ClO_2	chlorine dioxide
CMOS	complementary metal-oxide semiconductor
COC	chain of custody
CODEC	compression decompression (module)
CPU	central processing unit
CT	The product of multiplying the factors Concentration and Time. Has the units of mass*time/volume
Cu	copper
DAS	data acquisition system
DCMD	Decontamination and Consequence Management Division
DHS	Department of Homeland Security
DIMM	Dual In-Line Memory Module
DNA	deoxyribonucleic acid
DoD	Department of Defense
DOS	disk operating system
DQO(s)	Data Quality Objective(s)
DSL	digital subscriber line
DTRL	Decontamination Technologies Research Laboratory
DVD	digital video disc
EMS	ClorDiSys Solutions, Inc. Environmental Monitoring System
EPA	U.S. Environmental Protection Agency
ESD	electrostatic discharge
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
GMP	ClorDiSys Solutions, Inc. “Good Manufacturing Practices” ClO_2 gas generator system
GPU	graphics processing unit
H_2O_2	hydrogen peroxide
HCl	hydrochloric acid

HSPD	Homeland Security Presidential Directive
NOMAD®	Omega Engineering, Inc. RH and T data logger
HPV	hydrogen peroxide vapor
HSPD	Homeland Security Presidential Directive
IA&E	Independent Assessment and Evaluation
IPC	industrial printed circuit (boards)
KI	potassium iodide
KIPB	phosphate buffered potassium iodide solution
LCD	liquid crystal display
MEC	material/equipment compatibility
MFGB	Midget Fritted Glass Bubbler
N	Normality
NA	not applicable
N/A	not available
NB	nutrient broth
NGA	National Geospatial Intelligence Agency
NHSRC	National Homeland Security Research Center
NIST	National Institute for Standards and Technology
OSHA	Occupational Safety and Health Administration
PC	personal computer
PDA	Personal Digital Assistant
PDAQ	personal data acquisition (system)
PEL	permissible exposure limit
PLC	Programmable Logic Control
PVC	polyvinyl chloride
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
RAM	random-access memory
RH	relative humidity
S&T	Department of Homeland Security, Directorate for Science & Technology
SD	Standard Deviation
Sn	tin
SPI	Serial Peripheral Interface
SVGA	Super Video Graphics Array
T/RH	temperature/relative humidity (sensor)
TSA	tryptic soy agar
TWA	time-weighted average
USPS	United States Postal Service
UV-VIS	ultraviolet-visible
VHP	vaporized hydrogen peroxide

List of Units

°F	degree Fahrenheit
°C	degree Celsius
ft^3	cubic feet
g/min	grams per minute
hr	hour
L/min	liters per minute
m^3/h	cubic meter per hour
mg/L	milligrams per liter
mg/m^3	milligrams per cubic meter
mL	milliliter
ppb	parts per billion
ppm	parts per million
ppmv	parts per million by volume
scfm	standard cubic feet per minute
w/w	weight/weight

Executive Summary

In response to Homeland Security Presidential Directive 10 (HSPD-10), the Department of Homeland Security (DHS) and the U.S. Environmental Protection Agency (EPA), through its National Homeland Security Research Center (NHSRC), coordinated to develop a comprehensive program to provide scientific expertise and evaluation of actual and future potential decontamination technologies that could be used to recover and restore buildings and sensitive equipment contaminated by biological warfare agents.

STERIS VHP® hydrogen peroxide (H_2O_2) fumigation technology was shown to be effective against *Bacillus anthracis (B. anthracis)* spores when used to decontaminate two U.S. Government mail facilities in 2001.[1] The BioQuell HPV H_2O_2 fumigation technology has also been shown to be effective against *B. anthracis* spores in laboratory testing conducted by the National Homeland Security Research Center (NHSRC).[2] As part of an ongoing evaluation of the H_2O_2 decontamination method, this study was initiated by NHSRC and DHS and conducted at EPA's Decontamination Technologies Research Laboratory (DTRL) in Research Triangle Park, North Carolina. The goal was to provide information on the effects of potentially corrosive H_2O_2 gas on sensitive electronic components and materials, which substituted for the types of components also found in high-end military and commercial equipment such as medical devices and airport scanners.

Chlorine dioxide (ClO_2) fumigation has been used successfully for the remediation of several federal buildings contaminated by *B. anthracis* spores contained in letters.[1] To tie in the results of this study with previous research[5] on this alternative fumigation technique, ClO_2 decontamination was used on Category 4 materials (desktop computers and monitors).

Four categories of materials were defined by the principal investigator. Not included in this study were Category 1 materials, which are structural materials with a large surface area inside a typical building. While the field experience and subsequent NHSRC laboratory testing have clearly demonstrated that these materials in the building can have a significant effect on the ability to achieve and maintain the required concentration of fumigant, fumigation by H_2O_2 or ClO_2 has not been shown to affect their functionality.[3,4,18] The three categories examined in this study were:

- Category 2 Materials included low surface area structural materials that were expected to have minimal impact on the maintenance of fumigation conditions during a decontamination event. However, their functionality and use may be affected by the fumigation.
- Category 3 Materials included small, personal electronic equipment.
- Category 4 Materials included desktop computers and monitors.

By using visual inspection and tests on equipment function, this study documented the effects of different fumigation conditions on the H_2O_2 fumigation of all three categories of materials and equipment, and of ClO_2 fumigation on Category 4 Materials, commonly found inside large buildings and offices. Equipment and materials were subjected to a variety of fumigation conditions depending on the technology being used and the category of materials. The following H_2O_2 scenarios were conducted on all three categories of materials:

- BioQuell HPV with 35% starting RH with a 1 hour dwell time.
- STERIS 1000ED at 250 ppm H_2O_2 concentration for 4 hours with initial RH of 35% (total CT of 1000 ppm-hr).

Additional tests were conducted on Category 2 and 3 materials to document the impact of varying initial RH conditions and fumigation duration:

- BioQuell HPV with 65% and 10% starting RH, to determine the effect of higher and lower initial RH, respectively. The H_2O_2 equilibration concentration is inversely proportional to starting RH.
- BioQuell HPV with 35% starting RH and a 1.5x fumigation duration.
- STERIS 1000ED at 250 ppm H_2O_2 concentration for 1 hour with initial RH of 35% (total CT of 250 ppm-hr).

To allow for comparison of the effects of using H_2O_2 and ClO_2 fumigants on Category 4 materials (high-end equipment substitutes), the following ClO_2 fumigations were conducted:

- 3000 ppmv ClO_2 at standard conditions (75% RH, 75 °F) with a total CT of 9000 ppmv-hr (the basis for remediating sites contaminated with *B. anthracis* spores).

- 750 ppmv ClO_2 at standard conditions (75% RH, 75 °F) with a total CT of 9000 ppmv-hr (to analyze compatibility with FIFRA exemption requirements).

The results of this study indicate that there were no physical or functional effects on any of the Category 2 or 3 materials tested following H_2O_2 exposure, with one exception, which appeared to be an unrelated failure that could have occurred under normal use. These conditions included varying the initial RH, as well as the H_2O_2 concentrations and exposure duration. Category 2 and 3 materials appear to be compatible with both the BioQuell HPV and STERIS VHP® fumigations performed in this study.

None of the BioQuell HPV and STERIS VHP® fumigations showed any adverse effects for the Category 4 computers and equipment. BioQuell HPV was effective for inactivation of the biological indicators (BIs) used to provide an indication of the effectiveness of the fumigation in the bulk chamber and within each computer. STERIS VHP® was less effective in two of the three computers that were OFF and particularly ineffective in one of the computers that had been powered ON. One explanation for this observation might be that the higher temperature experienced in the ON computer decreased the RH and decreased the efficacy of the fumigant.

The corrosion and formation of powders seen in the ClO_2 fumigations agree with previous research conducted on this fumigant.[5] The lower concentration/ longer duration scenario resulted in more significant impacts than the higher concentration/shorter duration. These impacts included more severe and extensive corrosion, as well as monitor failure or discoloration. Being in the ON and active power state appears to promote the dislodging of corrosion off the central processing unit (CPU) heat sink by the fan. Because of this phenomenon, the CPU heat sink may be the primary, if not sole source of the corrosion.

Effects of fumigation for each category of material/ equipment are summarized below.

Category 2

No visual or functional changes were noted for Category 2 materials throughout the 12-month observation period following both BioQuell HPV and STERIS VHP® fumigations.

The printed paper and photographs for each fumigation condition remained visibly unchanged, and the color pigments were not adversely affected.

Each set of metals remained tarnish free, with no signs of rust or corrosion.

Each exposed smoke detector remained fully operational throughout the year after exposure; the battery terminals, resistors, and other components showed no signs of physical damage.

Exposed stranded wires remained tarnish-free 12 months after exposure.

None of the breakers or services from any test fell outside of the acceptable testing range.

Category 3

No visual or functional changes were noted for Category 3 materials throughout the 12-month observation period following both BioQuell HPV and STERIS VHP® fumigations, with the one exception of a PDA that failed to power on.

The CDs and DVDs were all unaffected by H_2O_2 exposure.

There were no signs of damage to any of the mechanical parts of the fax machine, and the same level of operation was maintained throughout the year.

No visual or functional changes were noted for the cell phones. Screen quality and operational parameters were unaffected.

One Personal Digital Assistant (PDA) would not power on, but the PDA that would not power on was from the low concentration (CT 250 ppm-hr) STERIS VHP® run. The high concentration run PDAs operated and appeared normal, indicating that this failure may not be related to the HPV exposure, but that this was a flawed PDA that could have failed under normal use.

Category 4

No visual or functional changes were noted for any Category 4 equipment that had been exposed to H_2O_2, regardless of concentration and run conditions.

Fumigation with ClO_2 resulted in internal and external corrosion of metal parts and the formation of acidic powders of chlorine-containing salts inside the computer casing. Parts affected by the ClO_2 fumigations included external and internal stamped metal grids, external metal slot covers, and the internal CPU heat sink.

The CPU was highly impacted in the lower concentration/longer duration fumigation; the higher concentration/shorter exposures were also impacted, but less so, particularly for the computers that have been ON and active versus ON and idle.

The CPU (aluminum alloy with a nickel-phosphorus coating) may be the primary, if not sole, source of the corrosion-generated powder. The graphics processing

unit (GPU) heat sink remained unaffected (single aluminum alloy), making the composition of the alloy very important to the impacts observed.

Greater amounts of dust were formed at lower but longer exposure ClO_2 concentrations. This dust may cause human health effects and the dust must be removed.

The vast majority of the failed components (83.3%) were related to the DVD drive, regardless of fumigation scenario. Most of the remaining failures (14%) were related to the floppy drive. However, comparison of the results with the control computers does not suggest that fumigation significantly affected the performance of the computers.

Profound effects under conditions of lower concentration/longer duration fumigation were seen when two of the three computers lost all functionality on days 109 and 212 following fumigation. Under conditions of lower concentration/longer duration fumigation, one of the computer monitors experienced discoloration (turned green). The other two monitors in this exposure set stopped functioning several months into the study.

Materials with the potential for damage include, but are not limited to, the following:

- Certain alloys of aluminum.
- Any device with optical plastic components, such as consumer-grade cameras, CD/DVD drives, laser pointers.
- Equipment containing extensive color-coded wire insulation.

1.0
Project Description Objectives

STERIS VHP® hydrogen peroxide (H_2O_2) fumigation technology used as part of the successful remediation of two U.S. Government mail facilities in 2001 that had been contaminated with *Bacillus anthracis* spores.[1] The BioQuell HPV H_2O_2 fumigation technology has also been shown to be effective against *B. anthracis* spores in laboratory testing conducted by the National Homeland Security Research Center (NHSRC).[2] Both technologies have been reported to be highly effective for spores on nonporous surfaces when sufficient sporicidal concentrations can be achieved (i.e., the generation capacity is sufficient to overcome the material demand for hydrogen peroxide). STERIS Corporation claims that the efficacy of their VHP® (vaporized hydrogen peroxide) technology is based upon maintaining a high concentration (>250 ppmv) of vaporous hydrogen peroxide in a volume without reaching condensation; their technology dehumidifies the space to less than 35 percent relative humidity (RH) before the introduction of vaporized hydrogen peroxide. BioQuell claims to rely on achieving micro-condensation on surfaces for efficacy, hence their technology rarely requires dehumidification before fumigation.

While many efforts are ongoing or have been completed with respect to investigation of material and sensitive equipment compatibility with STERIS VHP®, limited data to no independent data are available for sporicidal conditions for porous and nonporous surfaces relevant to public facilities. Most available data are related to Department of Defense (DoD) materials and equipment. No information has been made available related to the impact of BioQuell HPV (hydrogen peroxide vapor) fumigation on sensitive equipment. Due to the reported differences in the operation of the technologies, there is reason to suspect that impacts on materials and equipment might not be identical for both technologies.

While no significant impacts on structural materials of buildings have been determined in recent NHSRC work[3,4] no specific data related to the impact of decontamination on electronic equipment have been published for homeland security-related decontamination. Data on the effect of decontamination on electronic equipment are needed to further define guidelines for the selection and use of H_2O_2 for building and equipment decontamination, especially related to restoration of critical infrastructure. This project was performed to provide such information. In addition, to tie in the results of this study with previous research on an alternative fumigation technique, chlorine dioxide (ClO_2) decontamination was used on Category 4 materials (desktop computers and monitors).

1.1 Purpose

The main purpose of this work was to provide information to decision makers about the potential impact, if any, of the H_2O_2 decontamination process on materials and electronic equipment. This effort examined the impact on the physical appearance, properties, and functionality of certain types of materials and equipment. While the impact on specific items was addressed, the purpose was also to consider some items, particularly the computer systems and electronic components, as substitutes for high-end equipment such as medical devices and airport scanners. The optical disc drives in digital video disc (DVD) and compact disc (CD) drives, for instance, are similar to the laser diodes found in equipment such as fiber optic systems, deoxyribonucleic acid (DNA) sequencers, range finders, directed energy weaponry, and industrial sorting machines.

To provide comparative information and to tie this research into a previous study using ClO_2 as the potential decontamination technique,[5] desktop computers and monitors (Category 4 materials) were also fumigated with ClO_2 to would allow for comparison of the effects of these two fumigants on these high-end equipment substitutes. In the original research with ClO_2, inexpensive plastic CD and DVD components were found to experience the most frequent and serious failures.

1.2 Process

In order to investigate the impact of H_2O_2 and ClO_2 gases on materials and equipment under specific fumigation conditions, material was divided into four categories. Categories 2, 3 and 4 are described in Section 1.3; Category 1 materials (structural materials with a large surface area inside a typical building) were not addressed in this study. Materials in Categories 2 and 3 (low surface area structural materials and small, personal electronic equipment, respectively) were evaluated in-house before and periodically for one year after the date of exposure. Category 4 materials (desktop computers and monitors) were evaluated in-house before and immediately after fumigation. The sample

sets were then divided, with one of the samples for each condition (Control, STERIS, BioQuell, and ClO_2) sent to Alcatel-Lucent for in-depth analysis. The other samples remained in-house for evaluation over the course of a year.

1.2.1 Overview of the Hydrogen Peroxide (H_2O_2) Vapor Fumigation Process

Hydrogen peroxide vapor (HPV) has frequently been used to treat pharmaceutical manufacturing clean rooms and laboratory toxicology rooms. HPV was demonstrated to be effective against *Bacillus* spores, including the *anthracis* strain.[1,2] Hydrogen peroxide vapor generation systems have been adapted for potential use for the fumigation of larger volumes, including application to buildings.[6] In all cases, the H_2O_2 vapor is generated from a concentrated aqueous solution of hydrogen peroxide. The concentration is based on starting with 30 – 35 percent w/w H_2O_2 (shown effective in previous studies)[2,8]. However, this concentration is adjusted for the size of chamber being employed. For this study, the chamber was small in comparison to the previous studies, so the H_2O_2 vapor was generated from a 17.5 percent solution. At the end of the decontamination event, the H_2O_2 generator was turned off, and the fumigant was withdrawn from the space and generally passed over a catalyst (complementing the natural decay) to convert the VHP into water and oxygen, thus leaving no toxic residue.

Field use of the STERIS VHP® for fumigation of the Department of State Annex (SA-32) required H_2O_2 vapor concentrations (e.g., 216 ppm or about 0.3 mg/L) to be maintained for 4 hours at a minimum temperature of 70°F and maximum RH of 80 percent. NHSRC laboratory testing has shown effective inactivation (>6 log reduction) of *B. anthracis* spores on many building materials (with the exception of concrete and wood) at an H_2O_2 concentration of 300 ppmv for 3 – 7 hours (depending on material).[7] Testing with the BioQuell HPV showed effective inactivation on all nonporous materials with a dwell time of 20 minutes after equilibrium was achieved. However, the process under the specified test conditions was less effective (<6 log reduction) on most porous materials tested.[8]

The HPV in this study was generated using systems from two manufacturers: the STERIS Corporation VHP® 1000ED (Mentor, Ohio), and a Clarus™ L Small Chamber HPV Generator (BioQuell, Plc, Andover, England). The main difference between the two processes is that the BioQuell process permits higher RH values, attempting to achieve "micro-condensation" of a thin film of peroxide over the surface to be decontaminated. Inactivation of microbial agents is then achieved via a dwell time under H_2O_2 saturation conditions in the defined fumigation volume. Conversely, the STERIS process typically requires a low humidity in the space (e.g., less than 40% RH at the start of the fumigation), in an effort to keep the H_2O_2 in the vapor phase for improved penetration of substrate surfaces. Inactivation of microbial agents using the STERIS process relies on maintaining a vapor concentration for a specified contact time (e.g., achieving a minimum multiplication product of concentration and time (CT) value).[9] The STERIS label lists several concentrations and CT values, depending on the size of the chamber and the validation methods in place. The baseline CT for this work was 1000 ppm*hours, though 250 ppm*hours was also tested.

The STERIS VHP® 1000, their larger unit, has been used for decontamination of chambers and enclosed areas for 10 years and is applicable for rooms up to 6,000 ft^3 in size. The STERIS H_2O_2 products have been registered by the U.S. Environmental Protection Agency (EPA) under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). In more recent operations, multiple units were combined in a single operation to remediate significantly larger rooms. Scaled-up versions of the VHP® 1000 have been tested by STERIS, with multiple self-contained units being combined in a constructed flow system to treat volumes up to 200,000 ft^3 in actual applications.[1] The ability to treat such large volumes represents a significant enhancement in capability.

The STERIS VHP® 1000ED is a mobile bio-decontamination unit sized for small-scale decontamination of equipment such as glove boxes and biological safety cabinets. Sterilant injection and air flow rates are controlled by an Allen-Bradley Programmable Logic Control (PLC) system. The air in the chamber to be fumigated is first brought to a relative humidity less than 35 percent. Hydrogen peroxide (typically 35% w/w, but diluted to 17.5% in water for this study) is then flash vaporized in an air stream and injected at a rate between 1 and 12 g/min. The air flow rate can be controlled between 8 and 20 scfm. The system can be operated in either a closed or open loop system. Condensing conditions are avoided by keeping the H_2O saturation level at less than 80 percent. The H_2O_2 concentration is typically between 0.2 and 2 mg/L. The desired concentration is maintained for a set amount of time before aeration.

The BioQuell HPV is a mobile bio-decontamination unit that is sized for small-scale decontamination of equipment such as glove boxes and biological safety cabinets. Sterilant and airflow rates are controlled using a Siemens S7 PLC system. The Clarus™ L HPV

generator normally operates in a closed loop mode in which HPV is injected into the chamber at a fixed rate of 3 g/min of 30 percent w/w H_2O_2. The HPV is generated by releasing a metered stream of H_2O_2 solution onto a hot metal plate. The H_2O_2 solution is flash evaporated and diluted into air re-circulated from the decontamination chamber flowing at 20 m^3/h. Under normal conditions, a sufficient amount of HPV is injected to achieve "micro-condensation" based on prior experience and/or trial and error validation with chemical and biological indicators. Following the injection phase is a dwell time during which the sterilization is allowed to proceed to completion. The last step of the process is aeration, providing clean air to remove H_2O_2.

Previous studies of hydrogen peroxide vapor fumigation have shown that almost any material has the potential to reduce vapor concentration through sorption, catalytic decomposition, and reactive decomposition. Homogeneous hydrogen peroxide vapor decomposition in the gas phase has been found negligible at room temperature. However, hydrogen peroxide vapor is catalyzed by exposure to light. In addition to decomposition, hydrogen peroxide may be reversibly and irreversibly adsorbed onto exposed surfaces.[10]

1.2.2 Overview of the ClO_2 Fumigation Process

Fumigation with ClO_2 was added to the test matrix to relate results of the HPV compatibility tests to previous research.[5] Fumigation with ClO_2 has been shown in other efforts to be effective for the decontamination of biological threats on building material surfaces.[7,11] In past fumigation events for *B. anthracis* decontamination, the conditions set by FIFRA crisis exemptions required that a minimum concentration of 750 ppmv be maintained in the fumigation space for 12 hours until a minimum multiplication product of concentration and time (CT) of 9,000 ppmv-hours was achieved. Other important process parameters included a minimum temperature of 24 °C (75 °F) as a target and a minimum RH of 75 percent.

While the minimum effective CT has been maintained in subsequent events, substantial improvement in the ClO_2 fumigation process technology allowed for higher concentrations to be achieved in large buildings. The baseline fumigation with ClO_2 for *Bacillus* spores for the previous research was 3,000 ppmv within the volume for three hours to achieve the CT of 9,000 ppmv-hr. During this study, this condition was repeated for Category 4 materials. In addition, a 750 ppmv condition for 12 hours was also included for Category 4 materials to analyze compatibility with FIFRA exemption requirements.

ClO_2 is commercially generated by two methods; wet and dry. The wet method, such as the one used by Sabre Technical Services, LLC (Slingerlands, N.Y.; http://www.sabretechservices.com), generates the gas by stripping ClO_2 from an aqueous solution using emitters. The liquid ClO_2 is generated by reacting hydrochloric acid (HCl), sodium hypochlorite and sodium chlorite between pH 4.5 to 7.0. Sabre was the contractor for all ClO_2 fumigations related to the *B. anthracis* spore decontaminations following the 2001 anthrax mail incident[1] and are currently continuing to improve their process through mold remediation of facilities in New Orleans following hurricane Katrina. Sabre has fumigated structures as large as 14,500,000 ft^3 (United States Postal Service (USPS) facility, former Brentwood Processing and Distribution Center)[12] at CTs in excess of 9,000 ppmv-hr.[1]

The dry method, such as that used by ClorDiSys Solutions, Inc. (Lebanon, N.J.; http://www.clordisys.com), was used for this study. The dry method passes a dilute chlorine gas (i.e., 2% in nitrogen) over solid hydrated sodium chlorite to generate ClO_2 gas. ClorDiSys has performed several low level fumigations (~100 ppmv for a total of ~1200 ppmv-hours) of facilities for non-spore-forming organisms, and their technology is used widely in sterilization chambers.[13] No difference in the effectiveness of either of the two generation techniques to inactivate *B. anthracis* spores on building materials has been observed in laboratory-scale investigations.[11] Note that the wet technology is potentially "self humidifying", while the dry technique requires a secondary system to maintain RH. There are significant differences in experience in the scale of field operations of these two methods, as well as in generation capacity and state of advancement of technology application to large structures.

1.2.3 Material/Equipment Compatibility (MEC) Chambers

This task required that materials (computers and other potentially sensitive equipment) be exposed to H_2O_2 and ClO_2, at conditions shown to be effective for decontamination of biological and chemical agents on building materials and/or in facilities, to assess the impact (hence, compatibility) of the fumigation process on the material/equipment. Two identical isolation chambers (material/equipment compatibility chambers or MEC chambers) were used for these compatibility tests.

The HPV MEC control chamber served as the isolation chamber for the H_2O_2-exposed material/equipment for both H_2O_2 fumigation techniques. The ClO_2 MEC test

chamber served as the isolation chamber for the ClO_2-exposed material/equipment. Figure 1-1 shows the dimensions of the MEC chamber; a photograph of the MEC test chamber is shown in Figure 1-2. The three computer installation setup used for ClO_2 fumigations can be seen in Figure 1-1. For the H_2O_2 fumigations, only two computers were inside the chamber at a time, one open (OFF power; see Figure 1-3) and one closed (ON power).

Power is supplied within the chambers by the inclusion of two seven-outlet surge protectors (BELKIN seven-outlet home/office surge protector with six-foot cord, Part # BE107200-06; Belkin International, Inc.; Compton, CA) inside each chamber (not shown in Figure 1-1). The power cord from each surge protector penetrated the polyvinyl chloride (PVC) chamber material on the bottom back wall of the chamber and was sealed to the chamber to prevent the fumigant from leaking out.

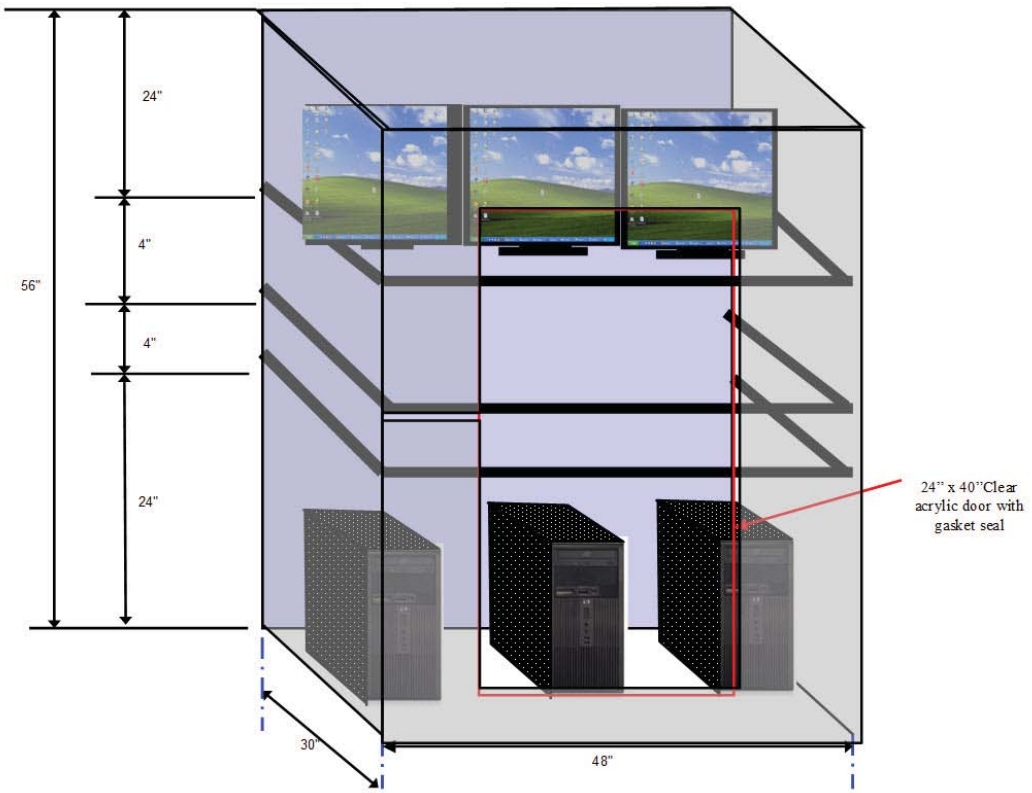


Figure 1-1. Schematic diagram of the MEC chambers.

Figure 1-2. Photograph of the MEC test chamber.

Figure 1-3. Open computer in HPV MEC chamber.

1.2.4 Laboratory Facility Description

The material compatibility testing was performed in the EPA's National Homeland Security Research Center (NHSRC), Decontamination and Consequence Management Division's (DCMD) Decontamination Technologies Research Laboratory (DTRL) located in Research Triangle Park, NC. This facility is equipped with multiple fumigation generation systems; the H_2O_2 and ClO_2 facilities are described below.

The chambers are made of opaque PVC with a clear acrylic door, which is fastened with a bolted flange. The door is covered with an opaque material during tests to prevent light-catalyzed reactions from taking place during exposure. The three removable shelves within the chamber are made of perforated PVC. Grounded woven wire mesh (Type 304 Stainless steel, 0.011" gauge wire) was placed on each shelf to dissipate any potential static electricity. The ground wire penetrated the chamber wall and was attached to the electrical service ground. Three fans were placed in each chamber to facilitate mixing.

1.2.4.1 Hydrogen Peroxide Facilities

The H_2O_2 facility is equipped with a BioQuell Clarus™ L small chamber HPV generator and ancillary sampling/monitoring equipment. The HPV concentration within the chamber was monitored using an Analytical Technology Corp. H_2O_2 electrochemical sensor (model B12-34-6-1000-1) coupled with a data acquisition unit to provide real-time concentration readings as well as data logging capability. The sensors are factory-preset to measure from 0 to 2000 ppm H_2O_2. Proper sensor operation was verified during the "dwell" phase of operation by iodometric titration on the HPV stream exiting the test chamber. To start the H_2O_2 delivery, the desired amount of 30 percent H_2O_2 was dispensed into the bottle inside the Clarus™ L. The mass of the hydrogen peroxide solution was recorded. The Clarus™ L unit withdraws the aqueous hydrogen peroxide solution from the bottle until it is empty.

This facility also contains the STERIS 1000ED VHP® generator. The built-in controllers store information such as the desired time for the cycle phases, operating pressure, H_2O_2 injection rate, airflow rates, and target RH. The controller also monitors the amount of H_2O_2 available in the reservoir and the dryer capacity. A prompt notifies the operator when the Vaprox cartridge needs to be changed and when the dryer needs to be refreshed through regeneration. The STERIS was connected to an external control system designed to maintain a constant concentration inside the chamber.

Both hydrogen peroxide generator systems were connected to a test chamber dedicated for hydrogen peroxide decontamination, and shared other support equipment. A C16 PortaSens II Portable Gas Detector equipped with a 00-1042, 0-10 ppm H_2O_2 detection cell (Analytical Technology, Inc., Collegeville, PA) was used as a room monitor and as a safety device before opening the chamber following aeration.

1.2.4.2 Clorine Dioxide Facility

This facility is equipped with a ClorDiSys Solutions, Inc., ClO_2 gas generation system (Good Manufacturing Practices (GMP) system) and ancillary sampling/monitoring equipment, test chambers, and support equipment. This system automatically maintains a constant target ClO_2 concentration in an isolation chamber (MEC Chamber) and injects ClO_2 (20 L/min of ideally 40,000 ppmv ClO_2 in nitrogen) when the concentration inside the chamber falls below a pre-set value. The MEC chamber is maintained at a set ClO_2 concentration, temperature, and RH. The ClO_2 concentration inside the chamber is measured by a ClorDiSys Solutions, Inc., photometric monitor located in the GMP unit, providing feedback to the generation system. A similar ClorDiSys Solutions, Inc. Emission Monitoring System (EMS) photometric detector is used to confirm ClO_2 concentrations.

1.3 Project Objectives

The primary objective of this study is to assess the impact of fumigation on materials, electrical circuits, and electronic equipment. Specifically, the fumigation conditions of interest are those using H_2O_2 or ClO_2 under conditions known to be effective for decontamination of materials and/or facilities contaminated with specific biological or chemical threats. Visual appearance of all items was documented before and after fumigation exposure. Most materials were not tested for complete functionality due to the multiplicity of potential uses. Specifically, this study focused on:

- the use of H_2O_2 or ClO_2 fumigation technologies,
- varying fumigation conditions, and
- the state of operation of the equipment (OFF, ON and idle, and ON and active).

Three categories of material and equipment were tested at the different fumigation conditions discussed in detail in Section 3.8. The categories of materials are separated according to the conditions of testing and analysis performed to assess the impacts. Category 1 materials are structural materials with a large surface area inside a typical building. While the field experience and subsequent NHSRC laboratory testing have clearly demonstrated that these materials in a building can have a significant effect on the ability to achieve and maintain the required concentration, fumigation has not been shown to affect their functionality.[14] Category 1 material was not included in this study. The three categories of materials that were investigated are described below.

1.3.1 Category 2 Materials

Category 2 materials include low surface area structural materials which are expected to have minimal impact on the maintenance of fumigation conditions within the volume. However, the functionality and use of Category 2 materials may be impacted by the fumigation event. The objective for this category of materials was to assess the visual and/or functional (as appropriate) impact of the fumigation process on the materials. The impact was evaluated in two ways. First, visual inspections at each fumigant condition (concentration, temperature, RH, and time) were made. These inspections were directed toward the locations considered most susceptible to corrosion and possible material defects due to the fumigation process. Second, functionality was assessed, as appropriate, for the material. Resistance was measured for metal coupons and stranded wires; circuit breakers and copper and aluminum services were overloaded to determine the time prior to tripping the breaker; sealants were checked for leaks; gasket elasticity was tested with a simple stress test; lamps were tested to see if the bulb would light; the digital subscriber line (DSL) conditioner was tested for transmission on a telephone or fax; and the smoke detector batteries and lights were checked and put through a smoke test. Printed documents and pictures were inspected for possible alteration of their content.

The visual inspections were documented in writing and by digital photography for each material prior to and after exposure in each fumigation event. Functional testing of materials was assessed before and after H_2O_2 treatment, then periodically after exposure, and again at year's end. Table 1-1 lists specifics of these materials and details the post-test procedures, where applicable. Items not tested for functionality after exposures are shown as "not tested" in the "Post-Fumigation Functionality Testing Description" column.

1.3.2 Category 3 Materials

Category 3 Materials include small personal electronic equipment. The objectives for this category were to determine aesthetic (visual) and functionality impacts on the equipment as a function of time post-fumigation. The assessment of the impact was visual inspection for aesthetic effects and evaluation of functionality post-fumigation. Inspection occurred monthly for five months, and then again at the one-year period, with the equipment stored at monitored (logged) ambient conditions throughout that time period. Visual inspections of the equipment were documented in writing and by digital photographs. Any indications of odor emissions were also documented. Further, the functionality of each piece of equipment was assessed comparatively with similar equipment that was not subjected to the fumigant exposure. Category 3 materials are listed in Table 1-2, with Table 1-3 detailing the post-test procedures.

Table 1-1. Category 2 Material Information and Functionality Testing Description

Material Name	Sample Dimension / Quantity	Description	Functionality Testing Description
Type 3003 Aluminum	2" x 2" x 0.0625" / 3 pieces	Metal Coupon	Triplicate coupons were stacked and the resistance was measured between the top and bottom coupon using an ohm meter.
Alloy 101 Copper	2" x 2" x 0.64" / 3 pieces		
Low Carbon Steel	1.5" x 2" x 0.0625" / 3 pieces		
Type 304 Stainless Steel	2" x 2" x 0.0625" / 3 pieces		
Type 309 Stainless Steel	1.5" x 2" / 3 pieces		
Type 316 Stainless Steel	2" x 2" x 0.0625" / 3 pieces		
Type 410 Stainless Steel	2" x 2" x 0.0625" / 3 pieces		
Type 430 Stainless Steel	1" x 2" x 0.012" / 3 pieces		
Yellow SJTO 300 VAC Service Cord[1]	12" long, 16 gauge, 3 conductor/ 3 pieces	Stranded Wire	The resistance of each wire was measured and recorded.
Steel Outlet/Switch Box	2" x 3" x 1.5" / 1 piece	-	Not tested.
Silicone Caulk	Approximately 1" long bead on the inside of a rectangular steel outlet/switch box	Sealant	Water was run into the corner of the outlet box with the sealant and the box was observed for leaks.
Gasket	0.125" thick flange foam rubber / 3 pieces	Gasket	Gasket was folded in half and examined for cracks.
Incandescent Light	60 Watt bulb / 3 pieces	Switch	A halogen light bulb was placed into the socket and the lamp was turned on. If the lamp failed to light the bulb, a new bulb was tested to verify that the switch was inoperable.
DSL Conditioner	NA / 1 piece	-	Simple connectivity was tested using a laboratory telephone through the conditioner.
Drywall Screw	1" fine thread, coated / 3 pieces	-	Not tested.
Drywall Nail	1.375" coated / 3 pieces	-	Not tested.
Copper Services	NA / 3 pieces	Copper and Aluminum Services	Services were tested at 15 amps (150% capacity) and timed to failure.
Aluminum Services	NA / 3 pieces		
Circuit Breaker	NA / 10 pieces	-	Breakers were tested at 20 amps (200% capacity) and timed to failure.
Smoke Detector	NA / 1 piece	9 Volt Smoke Detector	Battery was tested by pressing the button on the detector. In the hood, the alarm was tested by spraying the "Smoke Check-Smoke Alarm Tester" directly at the alarm. The light was checked to see if it was functioning.
Laser Printed Paper[2]	8.5" x 11" (15 pages)	-	Visually assessed for legibility.
Ink Jet Colored Paper[2]	8.5" x 11" (15 pages)	-	Visually assessed for legibility.
Color Photograph	4" x 6" / 3 pieces	-	Visually assessed for content.

Notes: "-" indicates "Material Name" and "General Description" are the same.
NA = not applicable.
1. The outside of the cord served as Housing Wire Insulation, and the three-stranded interior wires served as the Stranded Wires.
2. Test page can be found in Appendix E of the EPA Quality Assurance Project Plan (QAPP) entitled, "Compatibility of Material and Electronic Equipment with Chlorine Dioxide Fumigation," dated July 2007.

Table 1-2. Category 3 Materials

Materials	Description	Manufacturer	Model Number	Sample Size
Personal Digital Assistant (PDA)	Handheld	Palm	Z22	1 piece
Cell Phone	Pay-as-you-go Super thin flip superphonic ringtones full color screen	Virgin (Kyocera)	Marbl	1 piece
Fax/Phone/ Copier Machine	Plain-paper fax and copier with 10-page auto document feeder and up to 50-sheet paper capacity. 512KB memory stores up to 25 pages for out-of-paper fax reception	Brother	Fax 575	1 piece
Data DVD	Standard 21331 DVD Video	Warner Brothers	DVDL-582270B1	1 piece
Data CD	Standard Audio CD	CURB Records	DIDP-101042	1 piece

Table 1-3. Category 2&3 Materials Part Numbers and Vendors

Material	Part Number	Vendor
PALM Z22 Handheld Organizer		WalMart
Virgin Mobile Prepaid Marble Cell Phone - Black		WalMart
First Alert 9-Volt Smoke Detector	010921401	WalMart
Brother Fax-575 Fax/Copier		WalMart
CD: Today's #1 Hits (DIGI-PAK)		WalMart
DVD: Harry Potter and the Sorcerer's Stone		WalMart
Spring-Clamp Incandescent Light	1627K48	McMaster Carr
DSL Line Conditioner	1522T23	McMaster Carr
Smoke Alarm Tester	6638T21	McMaster Carr
Textured Alloy Aluminum Sheet, 0.063" thick, 12"x12"	88685K12	McMaster Carr
Alloy 101 Oxygen-Free Copper Sheet, 0.064" Thick, 6"X6"	3350K19	McMaster Carr
Type 316 Stainless Steel Strip W/2B Finish, 12"X12"	9090k11	McMaster Carr
Type 309 Stainless Steel Rectangular Bar, 2"X12"	9205K151	McMaster Carr
Miniature Stainless Steel Shape Type 430 Strip, 1"X12"	8457K49	McMaster Carr
Type 410 SS Flat Stock Precision Ground, 12"X24"	9524K62	McMaster Carr
Low Carbon Steel Round Edge Rectangular Bar, 1.5"X6'	6511k29	McMaster Carr
Type E 304 Stainless Steel Strip W/#3 Finish, 2"X12"	9085K11	McMaster Carr
Yellow SJTO 300 VAC Service Cord, 15 ft	8169K32	McMaster Carr
Steel Outlet/Switch Box	71695K81	McMaster Carr
4X6 Standard Color Print Glossy Finish		Walgreens
Gasket, round	14002	Sigma Electric
Drywall nail, coated, 1-3/8"	138CTDDW1	Grip Rite Fas'ners
Drywall screw, coarse thread, 1-5/8"	158CDWS1	Grip Rite Fas'ners

Table 1-4. Post-Fumigation Testing Procedures for Category 3 Materials

Material	Description of Testing Procedure
PDAs	The import and export capabilities were tested, and the screen condition was noted. Keypad and screen conditions were noted.
Cell Phones	Incoming and outgoing call capabilities were tested by ring and audio functions. Keypad and screen conditions were noted.
Fax Machines	Incoming and outgoing fax capabilities were tested, as were incoming and outgoing call functions.
DVD	The audio and visual functions were tested. A byte-level comparison was not performed on the media.
CD	The audio functions were tested by playing the first 10 seconds of each song. A byte-level comparison was not performed on the media.

1.3.3 Category 4 Equipment

Category 4 equipment includes desktop computers and monitors. The objective of testing this category of equipment (and materials) was to assess the impact of the fumigation conditions using a two-tiered approach: (1) visual inspection and functionality testing using a personal computer (PC) software diagnostic tool, and (2) detailed analysis for a subset of the tested equipment in conjunction with Alcatel-Lucent. This detailed analysis was performed through LGS Innovations, Inc. as the prime performer of a Chemical, Biological, and Radiological Technology Alliance (CBRTA) Independent Assessment and Evaluation (IA&E). The IA&E through CBRTA was funded by EPA and the Department of Homeland Security's Directorate of Science & Technology (S&T) via interagency agreements with the National Geospatial-Intelligence Agency (NGA, the executive agency for CBRTA at the time of the study).

One computer system of each test set (chosen by Alcatel-Lucent as potentially the worst performing) was sent to LGS for the IA&E. The other systems remained at the EPA facility and were put through a burn-in test (BIT) sequence five days a week, for eight hours a day, to simulate normal working conditions. All computer systems were evaluated using PC-Doctor® Service Center™ 6 (PC-Doctor, Inc.; Reno, NV) as the PC software diagnostic tool. The BIT sequence and PC-Doctor® Service Center™ 6 protocols were developed by Alcatel-Lucent specifically for this testing.While the impact on computer systems was being assessed directly in this effort, the purpose of the testing was to consider the systems as surrogates for many of the components common to high-end equipment (e.g., medical devices, airport scanners). The objective was to identify components and specific parts of components that may be susceptible to corrosion because of the fumigation process. This information can then be used to make informed decisions about the compatibility of other equipment that may have similar components or materials and can reduce further testing or uncertainty in the field application. The Category 4 equipment and materials listed in Table 1-4 were selected by Alcatel-Lucent as appropriate test vehicle sets to meet the objectives of this study.

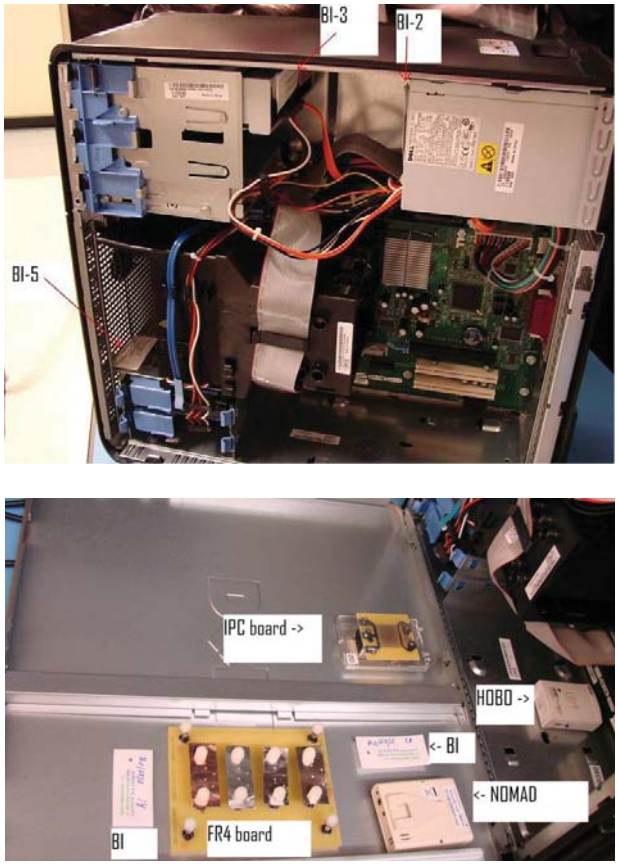
Table 1-5. Category 4 Tested Materials

Computer Component	Description	Additional Details
Dell™ OptiPlex™ 745	Desktop computer	See Appendix A for specifications.
Dell™ 15 inch flat panel monitor	Desktop monitor	See Appendix A for specifications.
USB keyboard and mouse	Desktop keyboard and mouse	See Appendix A for specifications.
Super Video Graphics Array [SVGA]	Computer display standard.	See Appendix A for specifications.
Metal coupons for H_2O_2 fumigations	Copper (Cu) Aluminum (Al) Tin (Sn)	These metals are used extensively in fabricating desktop computers. Silver (used for ClO_2 fumigations) was not used due to its high catalytic activity for H_2O_2. Provided by Alcatel-Lucent
Metal coupons for ClO_2 fumigations*	Copper (Cu) Aluminum (Al) Tin (Sn) Silver (Ag)	These metals are used extensively in fabricating desktop computers. Provided by Alcatel-Lucent
Cables	Computer power cord Monitor power cord Analog video cable	Standard cables
Industrial printed circuit board (IPC)	Circuit board (powered for H_2O_2 and ClO_2 fumigations)	Provided by Alcatel-Lucent

* All four metal coupons were included in the 3000-ppmv fumigations. The 750-ppmv fumigation was added later, and included only the Cu, Al and Sn coupons.

Further objectives in this study for Category 4 equipment and materials were to (1) provide an indication if localized conditions in an operating computer may be different from the bulk of the chamber and (2) obtain an indication of the potential impact the local conditions may have on the effectiveness of the H_2O_2 and ClO_2 fumigation processes to inactivate *B. anthracis* spores potentially located within the computer. For the first part of this objective, process parameter measurements in the bulk chamber and within the computers were compared. For the second part, biological indicators (BIs) were used to provide an indication of the effectiveness of the fumigation in the bulk chamber and within each computer.

BIs have been shown not to correlate directly with achieving target fumigation conditions for *B. anthracis* spores or inactivating *B. anthracis* spores on common building surfaces.[7] While BIs do not necessarily indicate achievement, they will sufficiently indicate a failure to achieve successful conditions. The locations of process measurement monitors (NOMAD® and HOBO®), metal coupons (on the FR4 Board provided by Alcatel-Lucent), IPC board and BIs within each computer are shown in Figure 1-4 (a) and (b). The NOMAD® (OM-NOMAD-RH, Omega Engineering, Inc., Stamford, CN) is an RH and temperature monitor with a built-in data logger. The HOBO® is an RH and Temperature monitor with data logger from Onset Computer Corp. (Pocasset, MA). The placement of these items within the computers was decided based upon the air flow within the chamber and the desire not to affect the operation of the computer. The items were affixed to the inside of the side panel of the computer case using self-adhesive hook-and-loop dots (P/Ns 9736K44 and 9736K45, McMaster-Carr, Atlanta, GA).



(a)

(b)

Figure 1-4. Location of NOMAD®, HOBO®, metal coupons, IPC board, and BIs within the (a) CPU and (b) panel.

2.0
Experimental Approach

2.1 DTRL Hydrogen Peroxide Analytical Capabilities

Table 2-1 lists the analytical techniques used to quantify H_2O_2 concentrations. The B12-34-6-1000-1 sensor was used to provide real-time concentration measurements, and control for STERIS fumigations. Microcondensation was verified visually for the BioQuell fumigations. An ATI Portasens was used as a room safety monitor.

Table 2-1. DTRL Hydrogen Peroxide Detection Methods

Manufacturer/ Organization	Method	Title	Equipment
Analytical Technology Corp.	Electrochemical detection	NA	B12-34-6-1000-1
Analytical Technology Corp.	Electrochemical detection	NA	C16 PortaSens II
American Association of Textile Chemists and Colorists (AATCC)	Modified AATCC Method 102-2007	Determination of Hydrogen Peroxide by Potassium Permanganate Titration	Midget Fritted Glass Bubbler (MFGB) containing 15 mL 5% H_2SO_4
OSHA	VI-6	Colorimetric Determination of Hydrogen Peroxide	MFGB containing 15 mL $TiOSO_4$

2.2 DTRL Chlorine Dioxide Analytical Capabilities

ClO_2 measurement capabilities within DTRL include Dräger Polytron 7000 remote electrochemical sensors (ClO_2/Cl_2), a HACH AutoCAT 9000 Amperometric Titrator (to facilitate wet chemical analysis for ClO_2 concentration measurements via a modification of American Water Works Association (AWWA) SM-4500-ClO_2-E), an Interscan Corporation LD223 dual range ClO_2 monitor (0-200 ppb; 0-20 ppm), and an Ion Chromatograph for use with the OSHA ID-202 method.

The ClO_2 measurement capabilities used in this study include the four analytical techniques that were assessed separately or on a one-to-one basis depending on the type of measurement needed (continuous versus extractive). The techniques are listed in Table 2-2.

Table 2-2. Chlorine Dioxide Analyses

Manufacturer/ Organization	Method	Title	Equipment
ClorDiSys Solutions, Inc.	UV-VIS adsorption	NA	Model GMP photometric monitor
ClorDiSys Solutions, Inc.	UV-VIS adsorption	NA	Model EMS photometric monitor
AWWA	Standard Method 4500-ClO_2 E Modified	Amperometric II	Collection in midget impingers filled with buffered potassium iodide (KI) solution
Dräger	Electrochemical Detection	NA	Model 6809665 chlorine electrochemical sensor with Polytron 7000 transmitter

The ClorDiSys photometric monitors were used for real-time analysis and control. The modified Standard Method 4500-ClO_2 E was used to confirm the real-time analyses. The Dräger Polytron 7000 sensors were used only for safety (i.e., room monitor). Additional details on the photometric monitors and modified Standard Method 4500 ClO_2 E can be found in Sections 3.1.2 and 3.1.3.

2.3 General Approach

The impact of the fumigant on the material and electronic equipment was investigated under different fumigation conditions (concentration, temperature, RH, and exposure time). The sampling strategies for each fumigation approach (STERIS, BioQuell, and ClO_2) are detailed in Sections 2.4.

The effect of the fumigation process on materials and electronic equipment was investigated using visual inspection and an assessment of functionality. All visual inspections were documented in writing and with digital photographs. Functionality testing was documented in writing (and by digital photography, where appropriate). Additionally, a subset of Category 4 test sets was subjected to a detailed IA&E by Alcatel-Lucent and was detailed in their final report, "Assessment and Evaluation of the Impact of Fumigation with Hydrogen Peroxide Technologies on Electronic Equipment," dated July 2009.[15] The results of the detailed IA&E on the original Category 4 test sets fumigated by ClO_2 were detailed in their final report, "Assessment and Evaluation of the Impact of Chlorine Dioxide Gas on Electronic Equipment," an EPA report with publication pending.[16]

2.4 Sampling Strategy

Two H_2O_2 vapor fumigation systems were independently included in this study. These systems are (1) the STERIS VHP® 1000ED and (2) BioQuell Clarus™ L HPV. The difference between these two technologies has been discussed in Section 1.2.1. The conditions under which each system was tested are discussed in Section 3.8.

2.4.1 STERIS VHP® 1000ED

The STERIS VHP® 1000ED generator, loaded with a 17.5 percent H_2O_2 cartridge, was connected to the MEC through the control system shown in Figure 2-1. The monitoring methods (H_2O_2 detection methods) employed were listed in Table 2-1. The computerized control system had a user-defined concentration setpoint of 250 ppm.

The STERIS VHP® 1000ED was programmed with the fumigation cycle shown in Table 2-3. When the control system received data from the Analytical Technology sensor that the H_2O_2 concentration was below the setpoint, valve V1 would be opened and valve V2 would be closed. As the concentration climbed above the setpoint, valve V1 would close and V2 would open, returning the H_2O_2 vapor back to the STERIS unit.

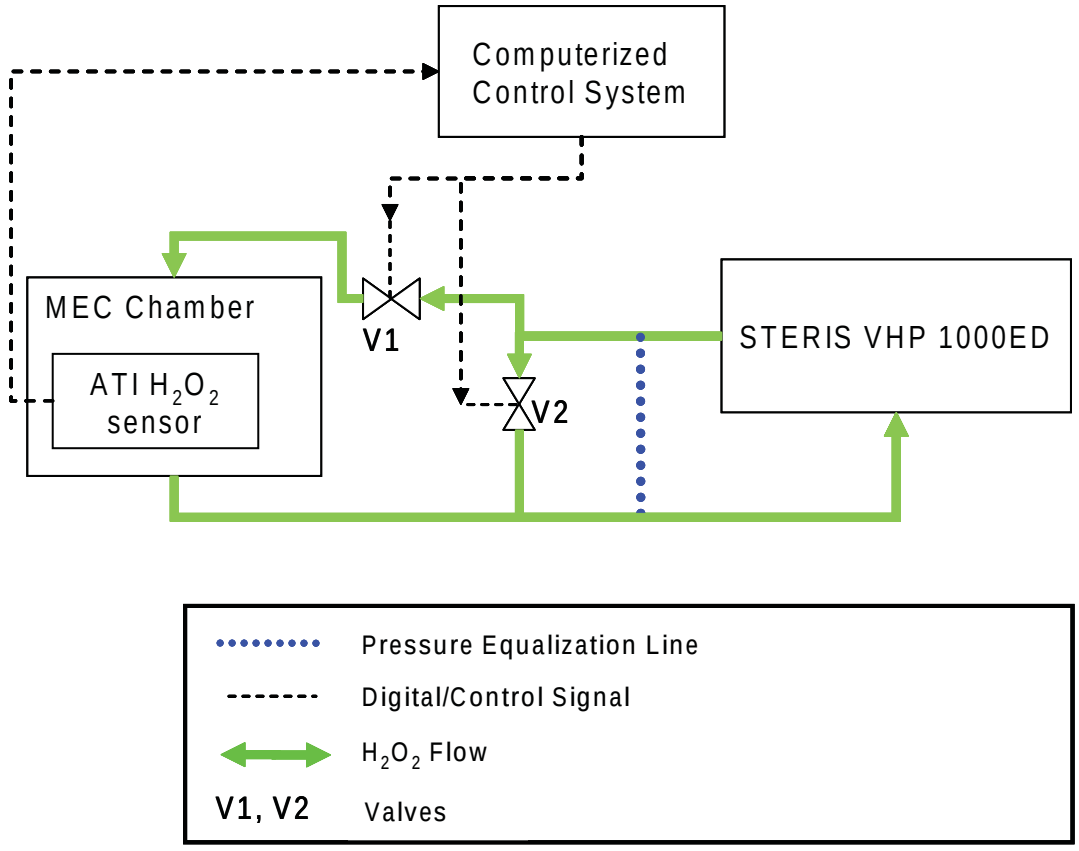


Figure 2-1. External STERIS control schematic

Table 2-3. Fumigation Cycle Used for the STERIS VHP® 1000ED

Phase	Time (minutes)	H_2O_2 Injection (g/minute)	Air Flow Rate (ft^3/minute)	Absolute Humidity (mg/L)
1. Dehumidify	0	0	17	2.30
2. Condition	4	2	8	NA
3. Decontamination	240	1	17	NA
4. Aeration	45	0	Not measured	NA

2.4.2 BioQuell Clarus™ L HPV

Method development trials were performed with the BioQuell Clarus™ L HPV generator prior to using this technology on the study materials and equipment. These trials were done using the MEC test chamber and a single set of surrogate Category 4 equipment for each trial. At the end of each trial test, the chamber was aerated for at least 2 hours and a minimum of 10 air exchanges. These tests suggested that saturation conditions could be achieved in the chamber at a starting RH of 30 ± 5 percent and an injection of 45 g of 31 percent H_2O_2. A dwell time of 60 minutes was chosen in collaboration with the manufacturer. These conditions became the target fumigation conditions for all BioQuell runs. Condensation conditions were confirmed visually, as the RH and H_2O_2 vapor concentrations within the chamber were monitored by an Analytical Technology H_2O_2 electrochemical sensor (Model B12-34-6-1000-1).

For the test fumigations, after the required H_2O_2 vapor was injected during the charge phase (within the 20 scfm closed-loop air flow), the blower was turned off to prevent recirculation during the dwell period. Recirculation through the heated sample lines injects more heat than the cooling system can handle. The H_2O_2 vapor concentration within the chamber was monitored using a second Analytical Technology Corp. H_2O_2 electrochemical sensor (Model B12-34-6-1000-1) to provide real-time concentration readings. Proper sensor operation was verified during the "dwell" phase of operation by iodometric titration on the HPV stream exiting the test chamber. RH and temperature in the chamber were measured using a Vaisala HUMICAP temperature and humidity sensor (Model HMD40Y, Vaisala, Helsinki, Finland). Three BIs were included in the test chamber and five within each computer; the BIs in the test chamber (outside the computer) also provided a quality assurance indication that successful fumigation conditions had been achieved.

2.4.3 ClO_2 Fumigation

The ClO_2 fumigations were performed at both 3000 ppmv and 750 ppmv. Figure 2-2 shows the generic schematic for the fumigation experimental set-up. The ClO_2 concentration in the test chamber was directly controlled with the GMP. The secondary fumigant monitor was the EMS. The wet chemistry samples, analyzed by modified Standard Method SM 4500-E, were taken every 30 minutes during the decontamination phase to confirm the concentration of ClO_2 in the MEC test chamber. The RH of the MEC chamber was controlled by a feedback loop with LabVIEW and a Vaisala temperature/RH (T/RH) sensor. When the RH reading fell below the desired setpoint, the data acquisition system (DAS) injected hot humid air into the MEC chamber.

Cooling was done by circulating cooling water just above the dew point (to prevent condensation) through small radiators equipped with fans. The temperature of the cooling water was raised or lowered to achieve the desired heat transfer. If necessary, the air exchange rate was also increased to aid in cooling: a blower removed the warm air from the chamber and replaced it with cooler air. The blower was also operated to prevent over-pressurization of the isolation chamber.

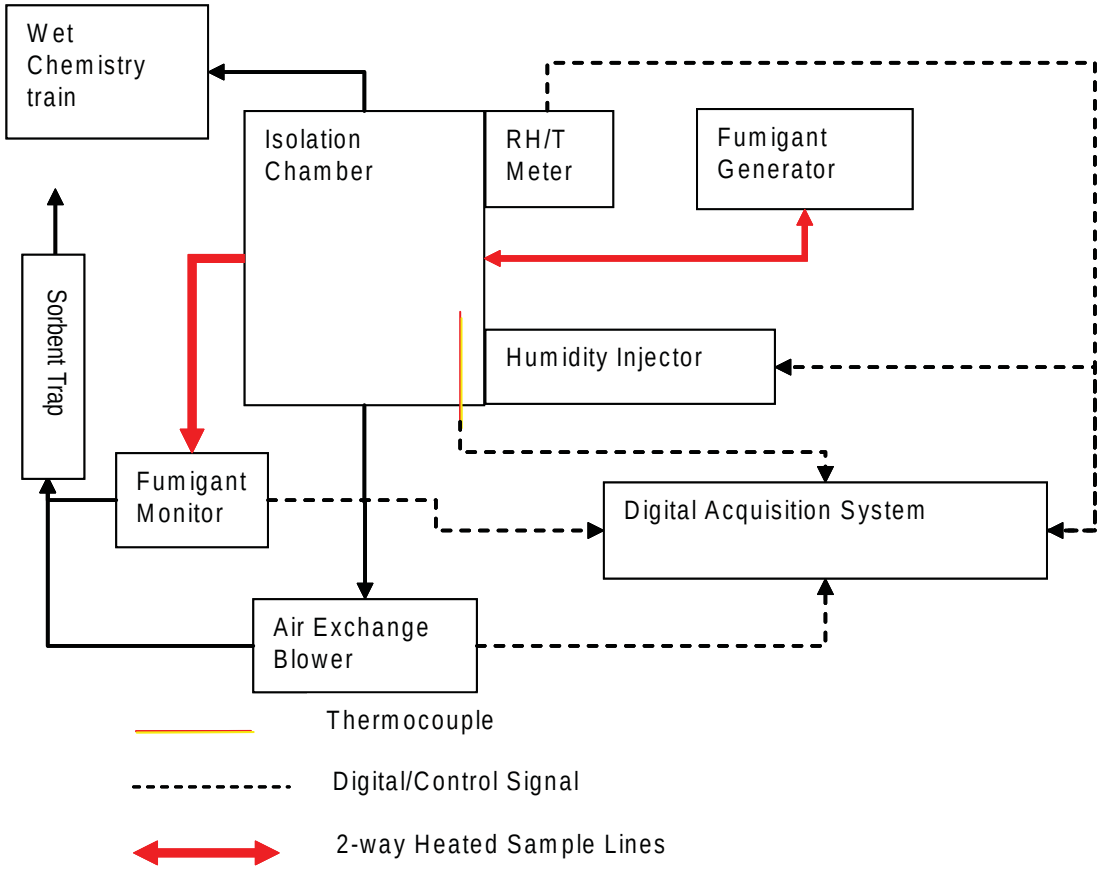


Figure 2-2. Experimental setup of the MEC test chambers

2.5 Sampling/Monitoring Points

Local variations in temperature were expected, especially due to the heat output of electronic devices while operating. This variation in temperature also affected RH. Because RH was a critical parameter in the effectiveness of the fumigant, the RH was checked by placing multiple NOMAD® and HOBO® T/RH sensors in and near fumigated equipment. The location of the sensor within the computers was shown in Figure 1-4. Alcatel-Lucent provided programmed NOMAD® sensors. Alcatel-Lucent downloaded the data once the sensors were returned to them at the completion of the fumigations. ARCADIS programmed the HOBO® sensors. Each of the HOBO sensors was checked against both a standard RH meter and the RH meter used to measure the bulk RH in the chamber for direct comparisons between the bulk and the localized RH after correcting for individual sensor bias. The purpose of the monitor points within the computers is for determination of temperature and RH gradients that might exist; the target temperature, RH, and ClO_2 concentration is that of the bulk chamber (e.g., not within equipment). The HOBO® sensors logged RH and temperature in real time, and the data were downloaded after the fumigation event was complete.

2.6 Frequency of Sampling/Monitoring Events

Table 2-4 provides information on the monitoring method, test locations, sampling flow rates, concentration ranges, and frequency/duration for the measurement techniques used.

Table 2-4. Monitoring Methods

Monitoring Method	Test Location	Sampling Flow Rate	Range	Frequency and Duration
GMP ClO_2 Monitor	MEC test chamber	5 L/min nominal	50-10,000 ppmv ClO_2	Real-time; 4 per minute
EMS Monitor	MEC test chamber	5 L/min nominal	50-10,000 ppmv ClO_2	Real-time; 6 per minute
Modified Standard Method 4500-ClO_2 E	MEC test chamber	0.5 L/min	36 -10,000 ppmv ClO_2	Every 60 minutes; 4 minutes each
Vaisala T/RH Sensor	MEC test chamber; GMP Box	NA	0-100 % RH -40 to 60 °C	Real-time; 6 per minute
NOMAD® T/RH Monitor	MEC test chamber, Inside Category 4 chassis	NA	5-95% RH -20 to 70 °C	Real-time; 4 per minute
HOBO® U10 T/RH Meter	MEC test chamber, Inside Category 4 chassis	NA	5-95% RH, -20 to 70 °C	Real-time; 6 per minute
Analytical Technology Corp. H_2O_2 Electrochemical Sensor	MEC test chamber during fumigation with BioQuell Clarus™ L or STERIS 1000ED system	NA	0-2000 ppm H_2O_2	Real-time; 6 per minute
Modified AATCC Method 102-2007	MEC test chamber	0.5 L/min	1.5 -10,000 ppm H_2O_2	Once per exposure, 4 minutes
OSHA VI-6 Monitoring Method	MEC test chamber	0.5 L/min	1.5 -10,000 ppm H_2O_2	Once per exposure, 10 minutes

NA – not applicable

2.7 Fumigation Event Sequence

2.7.1 H_2O_2 Fumigation

The STERIS 1000ED VHP® has two controllers that store information such as the desired time for the cycle phases, operating pressure, H_2O_2 injection rate, airflow rates, and target RH. The controllers also monitor the amount of H_2O_2 available in the reservoir and the dryer capacity.

After the H_2O_2 solution reservoir was filled, the decontamination cycle proceeded through four phases: Dehumidification, Condition, Decontamination, and Aeration. Hydrogen peroxide was first pumped from the cartridge to a reservoir. If the amount of H_2O_2 required for the cycle was greater than the capacity of the reservoir (1950 grams), the cycle was disabled.

- *Dehumidification Phase*: Dry, HEPA- filtered air was circulated to reduce humidity to the STERIS-recommended 30 ± 5 percent RH range to permit the necessary H_2O_2 vapor concentration to be maintained below saturation levels during the Condition and Decontamination Phases. The time to reach the targeted humidity increased with the volume of the enclosure.
- *Condition Phase*: The flow of dry, HEPA-filtered air continued while the H_2O_2 vapor was injected into the air stream just before the air stream left the bio-decontamination system with a controllable (1-12 g/min) injection rate. The condition phase facilitated reaching the desired decontamination concentration more quickly in larger sealed enclosures. The condition time was affected by sterilant injection rate and enclosure volume. This Condition Phase was optional and could be selected to reduce the total cycle time, especially for larger applications. Use of the Condition Phase does not reduce the time of exposure during the Decontamination Phase. The RH was expected to increase during this Phase, but the saturation level should not be expected to exceed 80 percent.
- *Decontamination Phase*. A constant flow of the H_2O_2 vapor/HEPA-filtered air mixture was maintained at the selected H_2O_2 injection rate, within the controllable range. RH had to remain below 80 percent to be considered a valid test.
- *Aeration Phase*. H_2O_2 vapor injection was stopped and the recirculation flow of dry HEPA-filtered air continued to reduce the vapor concentration within the enclosure. Following the Decontamination Phase, the drying system may have been needed to be refreshed. The time required to refresh the drying system depended upon cycle parameter selection, initial RH, humidity set points, and enclosure size.

The BioQuell Clarus™ L HPV generator normally operated in a closed loop mode and accomplished sterilization in four phases. In the first phase, called conditioning, the chamber air was dehumidified as

needed to less than 75 percent RH. Next, in the gassing phase, HPV was injected at a fixed rate of 3 g/min of 30 percent w/w H_2O_2 into the chamber. Under normal conditions, a sufficient amount of HPV was injected to achieve "micro-condensation" based on prior experience and/or trial and error validation with chemical and biological indicators. Once micro-condensation was achieved, sterilization is completed during the dwell time. Finally, the chamber was aerated with dry, HPV-free air to return the HPV concentration in the chamber to below the Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) for H_2O_2 of 1 ppm (1.4 milligrams per cubic meter [mg/m^3]) as an 8-hour time-weighted average (TWA) concentration.

The BioQuell Clarus™ L HPV generator is a "dual loop" generator. During the Conditioning and Aeration Phases, gas was withdrawn from the chamber and passed over an H_2O_2-decomposing catalyst and through a dehumidifier before returning to the chamber. During the gassing phase, the withdrawn gas was passed through a separate loop where it bypasses the catalyst and dehumidifier and is enriched with HPV before returning to the chamber. There was no air exchange during the dwell phase to reduce heat build-up. The Clarus™ L unit allowed the user to customize sterilization cycles in terms of quantity of H_2O_2 injected as well as the length of the different parts of the sterilization cycle. Test fumigations used a conditioning stage at 35 percent RH with an H_2O_2 injection quantity of 45 g and a dwell phase of 60 minutes.

2.7.2 ClO_2 Fumigation

For the ClO_2 fumigations, the decontamination cycle proceeded through several phases as described below: Pre-conditioning Phase, Exposure Phase, and Aeration Phase.

- *Pre-conditioning Phase.* During this phase, the ClO_2 MEC chamber was conditioned to maintain a constant pre-determined temperature and RH.
- *Exposure Phase.* The exposure phase in the test chamber was divided into two sequences:
  1. *Fumigant Charging Phase.* The fumigant charging phase corresponded to the time required to reach the target concentration of fumigant. The GMP directly fed the test chamber to reach the desired target ClO_2 concentration within the shortest time. The CT (ppmv-hours) of the charging phase was around one percent of the total CT accumulated in the overall exposure phase.
  2. *Exposure Phase:* The exposure phase corresponded to the set concentration time exposure (CT). Time zero was set as the time when the MEC test chamber reached the desired concentration (±10 percent standard deviation). The required CT was set to 9,000 ppmv-hour for the ClO_2 concentration (750 and 3,000 ppmv).
- *Aeration phase.* The aeration phase started when the exposure phase was completed (i.e., when the target CT had been achieved), proceeded overnight, and stopped when the concentration inside the chamber was below the OSHA PEL for ClO_2 of 0.1 ppmv (0.3 mg/m^3) as an eight-hour TWA concentration.

The phases of a fumigation event are graphically depicted in Figure 2-3. The times and demand rates for each phase shown are presented for illustration purposes only.

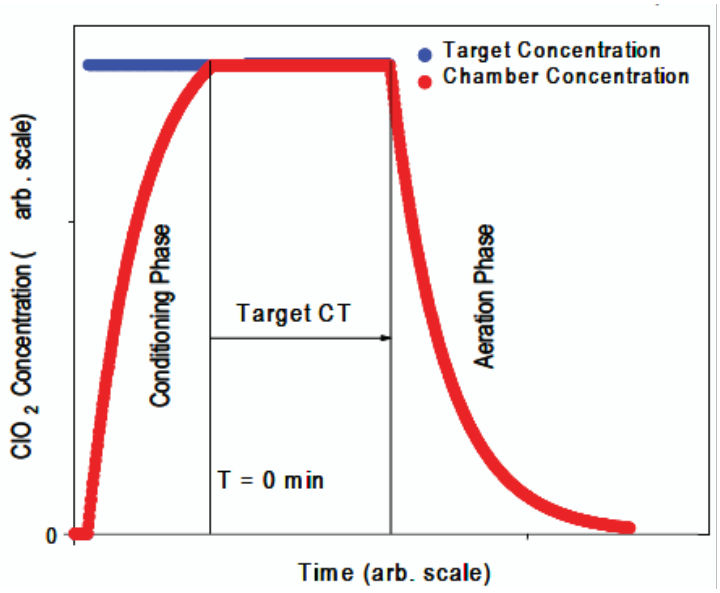


Figure 2-3. Material and equipment exposure time sequence

3.0
Testing and Measurement Protocols

Two separate isolation test chambers were used: the H_2O_2 MEC chamber for the HPV exposure and the ClO_2 MEC test chamber for the ClO_2 test conditions. No test chamber was used for the control tests (no fumigant). Tested materials and equipment were photographed before and after exposure and any visual changes noted, including color, legibility, and contrast. Off-gassing (i.e., noticeable odor) was also documented.

3.1 Methods

The HPV concentration within the HPV MEC chamber was measured using an Analytical Technology Corp. H_2O_2 electrochemical sensor and modified OSHA VI-6 (see Table 2-4). The photometric monitors (GMP monitor and EMS) and the extractive modified Standard Method 4500-ClO_2 E were used for monitoring ClO_2 concentrations in the ClO_2 MEC chamber. Table 2-2 specifies where these methods were used within the experimental setups.

In addition to H_2O_2 and ClO_2 measurements, other critical parameters measured were temperature and RH. Before each test, the Vaisala T/RH sensor used for control during testing was compared against a Vaisala T/RH sensor used as a reference (never exposed to fumigant). Secondary measurements in different locations within the chamber were measured by NOMAD® and HOBO® data loggers.

BIs were also included in the testing of Category 4 equipment. The use of BIs provided an indication of whether or not acceptable decontamination conditions were achieved due to variations in local conditions within the computers. The measurement equipment used in this project is described below.

3.1.1 Electrochemical Sensor for H_2O_2 Concentration Measurement

Hydrogen peroxide vapor concentration within the chamber was monitored using an Analytical Technology Inc. electrochemical sensor (Model B12-34-6-1000-1). The sensors are factory-preset to measure from 0 to 1000 ppm H_2O_2 with an accuracy of $\leq \pm 5\%$ of the measured value.

3.1.2 Modified OSHA Method VI-6 for H_2O_2 Concentration Measurement

OSHA Method VI-6 is a partially validated method for determining H_2O_2 concentrations in air. The method is intended for use at concentrations anticipated in the workplace, ranging from 1.5 ppm to 70 ppm. The method was easily scaled to the concentrations expected for this study by reducing the total volume of air collected from 100 liters to 2 liters, or alternatively, by reducing the fraction of the sample analyzed. While the method is intended for use with a colorimeter, the method describes the titration of the H_2O_2 standard using sodium thiosulfate. This titration method was used directly to determine the concentration in the recovered solution instead of using the colorimeter as an intermediary device. The modified method, based on OSHA VI-6 Sections 8.2 and 9.3, was initially performed for the BioQuell fumigations as described below. Due to difficulties encountered in obtaining valid results, this method was replaced with the Modified AATCC Method 102-2007described in Section 3.1.3.

1. A stock solution of titanium (IV) was prepared as follows: The hydrated $TiOSO_4 \cdot xH_2SO_4 \cdot xH_2O$ (MW > 402) was dried overnight in a desiccator. 5.5 g of the dried $TiOSO_4 \cdot xH_2SO_4 \cdot xH_2O$, 20 g of $(NH_4)_2SO_4$ and 100 mL of concentrated H_2SO_4 was placed in a beaker. The beaker was heated and heat gradually for several minutes until the chemicals were dissolved. Cool the mixture was to room temperature, pour carefully into 350 mL H_2O, filtered through an HA filter to remove any trace of turbidity, and then dilute to 500 mL. A 1:50 dilution of this stock solution was the titanium reagent or collecting solution.
2. 20 mL of the stock solution was added to two impingers.
3. H_2O_2 gas from the chamber was routed impinged into the stock solution in the impingers in series at a flow rate of 1 L/min for 2 minutes.
4. The 20 mL of stock solution from each impinger was combined into a 200 mL volumetric flask and impingers were rinsed thoroughly with deionized water. The flask was filled to the 200 mL mark.
5. The following solutions were transferred to a 125 mL Erlenmeyer flask.
   a. 4 mL recovered impinger solution
   b. 21 mL water
   c. 10 mL 4N H_2SO_4
   d. 6 mL 1N KI
   e. 3 drops 1N $(NH_4)_6Mo_7O_2$
6. The solution was titrated to a very faint yellow with

0.1N $Na_2S_2O_3$ and then 1 mL starch solution was added to produce a blue color. The titration was continued until the solution is colorless.

7. The total amount of $Na_2S_2O_3$ required to reach the colorless end point was determined
8. The volume of sodium thiosulfate used in the titration was recorded.

The normality of the H_2O_2 solution was calculated by multiplying one eighth of the volume of sodium thiosulfate used by the normality of the titrating solution. The H_2O_2 concentration in ppm was calculated by multiplying N(H_2O_2) by 17,000.

3.1.3 Modified AATCC Method 102-2007 for H_2O_2 Concentration Measurement

Modified AATCC Method 102-2007 - Determination of Hydrogen Peroxide by Potassium Permanganate Titration – was used for determining most of the H_2O_2 concentrations in air. This titration procedure is described below.

1. Two impingers were filled with 20 mL of 5% sulfuric acid (H_2SO_4)
2. The desired volume of gas was drawn through the sampling train and the volume was recorded.
3. 40 mL of solution from the impingers was added to 150 mL of DI water
4. A titration was done to the first permanent pink color with 0.3 N potassium permanganate ($KMnO_4$).
5. The mL $KMnO_4$ required was recorded.

The reaction is:

$$5\ H_2O_2 + 2\ KMnO_4 + 4\ H_2SO_4 \rightarrow 2\ KHSO_4 + 2\ MnSO_4 + 8\ H_2O + 5\ O_2$$

The calculation of the H_2O_2 concentrations in air was performed by Equation 3-1:

$$\text{mol } H_2O_2 = (\text{mL } KMnO_4) \times (N) \times 0.0025 \qquad (3\text{-}1)$$

where

N = normality of $KMnO_4$ solution

The conversion to ppmv is shown in Equation 3-2:

$$H_2O_2 \text{ concentration in ppmv} = (\text{mol } H_2O_2) \times (24.5 \text{ L/mol at } 298 \text{ K})/(\text{liters of gas sampled}) \qquad (3\text{-}2)$$

Equation 3-2 shows the combined, simplified equation that was used to calculate the H_2O_2 concentrations in air:

$$H_2O_2 \text{ concentration in ppmv} = [\text{mL } KMnO_4 \times N \times 0.06125] / [\text{liters of gas sampled}] \qquad (3\text{-}3)$$

3.1.4 Photometric Monitors

The ClorDiSys EMS monitor is identical to the photometric monitor built into the ClorDiSys generator (GMP), which was used to generate the ClO_2 in this study. Comparisons of the two instruments performed in a separate study indicated the two instruments read within 3 percent of one another with an R^2 value of 0.99.[17]

The monitors were photometric systems operating in absorbance mode with a fixed path cell. An internal pump in the EMS and GMP provided flow of the test gas from the sample point to the analytical cell. The maxima and minima of an unspecified and proprietary ClO_2-specific absorbance band were monitored. These numbers were then used to calculate the absorbance at this analytical band. Before delivery, calibration was performed with National Institute for Standards and Technology (NIST)-traceable transmission band pass optical filters (385/0.9CU; Optek-Danulat, Inc., Essen, Germany). The photometric systems included a photometer zero function to correct for detector aging and accumulated dirt on the lenses. Daily operation of the photometers included moments when clean, ClO_2-free air was being cycled through the photometers. If the photometer read above 0.1 milligrams per liter (mg/L) during these zero air purges, then the photometer was re-zeroed. Problems arising from condensation when sampling under high temperature or high RH conditions were addressed by heating the sample lines and the photometer cell. Table 3-1 provides instrument specifications.[18,19]

Table 3-1. ClorDiSys EMS/GMPs Photometric Monitor Characteristics

Parameter	Value	
	mg/L	ppm
Precision (SD)	±0.1	±36
Range	0.1-30	50-10,900
Accuracy (SD)	±0.2 from 0.5-50	±72 from 181-18,100
Resolution	0.1	36

SD = Standard Deviation

3.1.5 Modified Standard Method 4500-ClO_2 E

Standard Method 4500-ClO_2 E is an amperometric titration suitable for aqueous ClO_2 concentrations between 0.1 to 100 mg/L. This method does not address gas-phase sampling. The full method is quite complex because a multi-titration scheme is used to differentiate several chlorine-containing analytes. A modification of this method to incorporate gas-phase sampling uses a buffered potassium iodide bubbler for sample collection and restricts the official method to a single titration based upon Procedure Step 4b.[20] The single titration analyzes the combined chlorine, chlorine dioxide, and chlorite as a single value. The single titration can only be applied where chlorine and chlorite are not present. Since the modified method (modified Standard Method 4500-ClO_2 E) described below is applied to gas-phase samples, the presumption of the absence of chlorite and chlorate is quite valid. When the results from this method agree with the EMS and GMP values, no chlorine is present. However, chlorine is considered to be present when the titration results are higher than the EMS and GMP values.[17]

A discussion of the modified Standard Method 4500-ClO_2 E used in this test plan can be found in the approved QAPP entitled, "Fumigant Permeability and Breakthrough Curves, Revision 1, April 2006."[21] Modified Standard Method 4500-ClO_2 E is performed as described below.

1. 20 mL of phosphate buffer solution, pH 7.2 with KI (25 g KI/ 500 mL of buffer phosphate) (KIPB solution) was added to two impingers.
2. ClO_2 gas from the chamber was routed into the KIPB solution in the impingers in series at a flow rate of 0.5 L/min for four minutes.
3. 20 mL of KIPB solution from each impinger was combined into a 200 mL volumetric flask and the impingers were rinsed thoroughly with deionized water. The flask was filled to the 200 mL mark.
4. 5 mL of the resulting solution was diluted to 200 mL with deionized water and 1 mL of 6 N HCl was added to the solution.
5. The solution was placed in the dark for five minutes.
6. The solution was titrated with 0.1 N sodium thiosulfate (N = 0.1) from yellow to clear.
7. The volume of sodium thiosulfate used in the titration was recorded. Conversion calculations from titrant volume to ClO_2 concentration were based on Standard Method 4500-ClO_2 E.

   ClO_2 (mg/L) = Volume of sodium thiosulfate (mL) x N x 13490 /0.025 (fraction of gas titrated) (3-4)

   where N = Normality.

This method removed many of the possible interferences listed in Standard Method 4500-ClO_2 E.[20] The initial presence of KI in excess prevented iodate formation: iodate formation can occur in the absence of KI and leads to a negative bias. The presence of the pH 7 buffer during impinging prevented oxidation of iodide by oxygen which occurs in strongly acidic solutions. Other interferences were unlikely to be a problem in this application, as the presence of manganese, copper, and nitrate was unlikely in a gaseous sample.

The second impinger filled with buffered KI solution was added in series to reduce the likelihood of breakthrough. The second impinger was not analyzed independently but was combined with the first impinger for analysis. System blanks were analyzed, on a daily basis, by titration of the KIPB sample. When titration yielded a volume of titrant greater than 0.5 percent of the expected value of the impinged sample, a new KIPB solution was mixed to provide a lower blank value.

3.1.6 Temperature and RH Measurement

Temperature and RH measurements were performed with three types of sensors: the Vaisala HMP50 transmitter, the NOMAD® logger, and the HOBO® U10 logger. The Vaisala transmitter was used for the real-time control of humidity and was placed at a point distant from the steam injector. The NOMAD® and HOBO® loggers were put in various places within the MEC test and control chambers and within computers (Category 4) to provide a map of humidity and temperature conditions. The specifications of these instruments are shown in Table

Table 3-2. RH and Temperature Sensor Specifications

Instrument	Vaisala	NOMAD®	HOBO®
RH Range	0 to 98%	20 to 90%	25 to 95%
RH Accuracy – 0 to 90%	±3%	±5% at 60% RH and 25 °C	± 3.5%
RH Accuracy – 90 to 98%	±5%	Unknown	Unknown
RH Resolution	0.001% [1]	Unknown	0.07%
Temperature Range	-10 to 60 °C	0 to 50 °C	-20 to 70 °C
Temperature Accuracy	± 0.6 °C @ 20 °C	± 1.8 °C	± 0.4 °C @ 25 °C
Temperature Resolution	0.001 °C [1]	<1 °C	0.1 °C

[1] Vaisala resolution estimated from 22-bit resolution of personal data acquisition system (PDAQ).

Repeated exposure to fumigation conditions degrades both instruments. In the case of the Vaisala, the RH sensor becomes corroded and the higher resistance results in inaccurate RH readings. Corroded sensors were detected and replaced during the RH sensor comparisons before each test (see below). In the case of the NOMAD® and HOBO®, the fumigant likely corrodes the circuit board so that download of the logged data is sometimes impossible. To help prevent this reaction, the NOMAD® T/RH sensors were used only once before being replaced.

A separate, calibrated Vaisala HMP50, never exposed to fumigation, was used as an independent reference. Before each test, each Vaisala sensor was compared to the reference sensor at ambient (~40% RH) and at 75 percent RH. If the Vaisala differed from the reference by more than 4 percent, then the removable RH sensors were replaced (independent of the rest of the transmitter). The RH measurements from the NOMAD® and HOBO® sensors were used only for qualitative comparisons with the Vaisala sensor.

3.1.7 Biological Indicators (BIs)

Biological indicators (BIs) are intended to mimic the response of difficult-to-kill spores such as *B. anthracis*. Therefore, each fumigation method has a recommended or preferred BI. The following sections describe the BIs for HPV fumigations using the Clarus™ BioQuell system or the STERIS technology, and for the ClO_2 fumigations.

3.1.7.1 BIs for HPV Fumigations

Both the BioQuell Clarus™ L Small Chamber HPV Generator and the STERIS VHP® 1000ED bio-decontamination systems were tested with a highly resistant nonpathogenic microorganism, *Geobacillus stearothermophilus,* inoculated onto stainless steel coupons (population 10^6 spores) and contained within a Dupont™ Tyvek® pouch.

3.1.7.2 BIs for ClO_2 Fumigations

The BIs for ClO_2 fumigations were acquired from Apex Labs (Sanford, NC). The BIs were received as *Bacillus atrophaeus* (*B. atrophaeus)* spores, nominally $1x10^6$, on stainless steel disks in Dupont™ Tyvek® envelopes. These BIs have been used extensively in NHSRC-related ClO_2 fumigation efficacy testing for *B. anthracis* spores deposited onto building materials. While it is easier to inactivate the spores on the BIs than on most materials, BIs can provide a suitable indication of failure of the inactivation of *B. anthracis* on surfaces. Thus, failure to inactivate the BIs suggests that conditions required to inactivate spores on environmental surfaces were not achieved.[11] Further, the inactivation of *B. anthracis* spores on building materials and *B. atrophaeus* spores on the stainless steel BIs is highly sensitive to RH. For inactivation with ClO_2, spores typically require a minimum of 75 percent RH for effective kill conditions.[12]

3.1.7.3 BI Handling and Analysis Procedures

Within operational computers, the higher local temperatures expected would cause a localized area with lower RH than the bulk of the chamber. Therefore, BIs were placed in the bulk chamber and within each computer in order to assess a difference in the failure to achieve the appropriate decontamination conditions. Five BIs were collocated in each computer (see Figure 1-4) and in the MEC test and control chambers. After removal from the chambers and computers following testing, the BIs were transferred to the Air Pollution Prevention and Control Division's (APPCD's) Microbiology Laboratory. The transfer was accompanied by a chain of custody (COC) form for each group of five BIs.

In the Microbiology Laboratory, the BIs were transferred aseptically from their envelopes to a sterile conical tube (Fisherbrand, Thermo Fisher Scientific, Inc., Waltham, MA) containing at least 25 mL of nutrient broth (NB) (BBL Dehydrated Nutrient Broth, BD Diagnostics Systems, East Rutherford, NJ). Each BI was placed in an individual sample tube; both positive and negative controls were analyzed in conjunction with each test group for quality assurance. The tubes were incubated for seven to nine days (at 35 °C ± 2 °C for *Bacillus atrophaeus* and at 55 °C ± 2 °C for *Geobacillus stearothermophilus)*, then recorded as either "growth" or "no growth" based upon visual confirmation of the presence of turbidity in the liquid media in the tubes. Tubes with growth turned the NB very cloudy and the consistency of the NB was changed. Contents of all

tubes were plated on tryptic soy agar (TSA) (Remel Inc., Lenexa, KS) to confirm that any growth in the tube was indeed *B. atrophaeus/Geobacillus stearothermophilus* and not another organism that had contaminated the samples. Using aseptic techniques, the TSA plates were incubated overnight at 32 °C or 55-60 °C, depending on organism. During analysis, the target organisms are identified using colony morphology. Gram stains are used as secondary QC to confirm that experimental growth consists of gram positive spore-forming bacteria. Both positive and negative controls were used to confirm that *B. atrophaeus and Geobacillus stearothermophilus* growth on TSA was consistent.

3.1.8 Visual Inspection

Visual inspection focused mainly on the expected effects of fumigation: any changes in color and any occurrence of corrosion. Color change could also affect legibility of printed paper materials. Digital photographs of each coupon or material were taken prior to fumigation. After fumigation, digital photographs were taken to document the condition of the materials/equipment. Category 4 equipment (computers) was photographed monthly to document changes over time. Some Category 2 and 3 equipment was partially dismantled (e.g., faxes and smoke detectors) in order to take digital photographs of the equipment inside the casing. This dismantling was done at an approved electrostatic discharge (ESD) station. Changes in color or observed corrosion or corrosion products (i.e., powder inside a casing) were noted. Any changes in legibility or contrast of materials after fumigation were recorded as well.

3.1.9 Functionality Testing

All electronic equipment in Categories 3 and 4 underwent functionality testing prior to and after fumigation, as did selected materials from Category 2, as appropriate. These tests were detailed in Tables 1-1 and 13 for the Category 2 and 3 materials, respectively. For the Category 4 equipment, the protocols for the computer setup and analysis were developed by Alcatel-Lucent for the specific equipment being tested (see Appendix D of the EPA QAPP entitled, "Compatibility of Material and Electronic Equipment during Fumigation," dated September 2008).[22]

All Category 2 and 3 materials were analyzed before and immediately after fumigation, then periodically after exposure, and again at year's end. Based on observations of effects, the post-fumigation testing schedule was modified to reduce the number of evaluations in a way that did not compromise achieving the overall objectives of this project. During the one-year period, all equipment was stored in an indoor office/laboratory environment with logged temperature and RH.

Category 4 equipment was tested in triplicate. After the post-fumigation functionality test, one of each set of Category 4 computers was sent to Alcatel-Lucent for in-depth failure analysis; the remaining computers remained at DTRL for continued functionality testing for one year. During the one-year period, the computers and monitors were stored in an indoor office/laboratory environment with logged temperature and RH. The post-fumigation analysis continued monthly for these pieces of Category 4 equipment, with one exception. Computers fumigated with the BioQuell method were not analyzed the first month after fumigation, but were then analyzed monthly afterwards.

The computer systems were maintained in the operational (ON) state and were put through a BIT sequence five days a week, for eight hours a day, to simulate normal working conditions. Functionality testing was done by running a predefined routine specific to each of the items. These routines were documented for each item and maintained in the item's log book or on test report sheets. For the computer systems, PC-Doctor® Service Center™ 6 was run to complete a hardware and software diagnostic investigation. The BIT sequence and PC-Doctor® Service Center™ protocols were developed by Alcatel-Lucent specifically for this testing. The results of the diagnostic protocol were maintained in the appropriate log book.

3.1.10 Detailed Functionality Analysis (Subset of Category 4)

The assessment of the impact of fumigation on Category 4 equipment was performed in conjunction with Alcatel-Lucent through LGS Innovations, Inc. as the prime performer of a CBRTA IA&E. Four computers − one computer and monitor from each of the test conditions (control, STERIS and BioQuell H_2O_2 fumigations, and ClO_2 fumigations) − was sent to Alcatel-Lucent for detailed functionality testing. The worst-performing computer from each of the triplicate test sets was chosen for this in-depth testing. These computers and monitors, after undergoing the initial pre-/post-fumigation visual inspection and functionality screening, were preserved and shipped as detailed in Section 3.6. The order of increasing level of analysis was (1) aesthetic and functionality evaluation (energize, run diagnostic protocol), (2) visual inspection and more advanced diagnostics to identify affected components, (3) modular investigation, and (4) cross-section and failure mode analysis. The metal coupons and IPC boards were also analyzed by Alcatel-Lucent.

3.2 Cross-Contamination

The two isolation chambers, HPV MEC and ClO_2 MEC, were set up in two different laboratories. There was no contact between the two chambers in order to eliminate any potential exposure of either MEC chamber to the

other fumigant. Protocols provided by Alcatel-Lucent prohibited cross-contamination of corrosion particles by limiting the use of each test device to a single computer. BIs and wet chemistry samples are not expected to be affected by cross-contamination.

3.3 Representative Sample

Category 4 materials are as identical as possible to materials tested under a previous study using ClO_2 as the fumigant.[5] Materials and equipment were chosen as representative of, or as surrogates for, typical indoor construction materials or modern electronic devices. Each material or piece of equipment was tested in triplicate for representativeness. After initial inspection to confirm the representativeness of the Category 4 equipment post-treatment under the test conditions, the set that fared the worst from each test condition was sent for the detailed analysis performed by Alcatel-Lucent. The initial inspection was an assessment for visual changes and PC diagnostic using PC-Doctor® Service Center™ 6.[23]

3.4 Sample Preservation Method

Test samples (i.e., materials and equipment) were stored in temperature- and RH-controlled, indoor ambient laboratory conditions until testing was performed. All samples, both test and control, were stored under the same conditions prior to and after the fumigation event.

The Category 4 items, specifically the computers and monitors, were treated differently from the items included in the other categories. The computers and monitors were removed from their original packaging, labeled with a designated sample number (see Section 3.5), and set up according to the protocol provided by Alcatel-Lucent. After the pre-test analysis, the computers were dismantled, placed in individual anti-static and anti-corrosion bags (Corrosion Intercept Technology; http://www.staticintercept.com/index.htm) sealed and stored until reassembly and preparation for the fumigation event. The computers were also dismantled and bagged during transport to and from the MEC chambers.

After exposure to the test conditions, the Category 4 equipment was transferred back to the individual anti-static and anti-corrosion bag for transportation to an appropriate area (ESD work station, E-288, see below) in which the computers and monitors could remain energized and operated over the course of a year to continually assess delayed effects due to the test conditions under which they were treated. Category 2 and 3 materials and equipment were also transferred to E-288. The temperature and RH in the area were monitored and logged. Each computer and monitor underwent visual inspection and initial diagnostics with PC-Doctor® Service Center™ 6. The protocols for running PC-Doctor® Service Center™ 6 were developed and provided by Alcatel-Lucent, specifically for the equipment included in this testing.

After at least one month of testing, Alcatel-Lucent identified the computer from each test condition (Control, BioQuell, STERIS, and ClO_2) that they wanted shipped to them for the detailed analysis. The computers selected for shipment were usually the worst-performing computer within each test condition set.

Before fumigation of the computers, the systems were opened to insert a T/RH monitor (NOMAD®) and BIs in each desktop case. The Category 4 metal coupons and IPC board were also placed in each computer case. The location and method of fastening the equipment inside the case were specified by Alcatel-Lucent. The insides of the desktop computers were digitally photographed. To maintain the integrity of the computer by avoiding static electricity, an ESD Station was established for work on the computers. An ESD station was set up in E-288 (EPA Facility, Research Triangle Park, NC) and a second sub-station (smaller) next to the MEC test chambers in H-224 and H-222 (EPA Facility, Research Triangle Park, NC). Training on this work station in E-288 was provided by Alcatel-Lucent on July 18, 2007, prior to the start of the original ClO_2 fumigation testing. In general, the station consisted of an electrostatic discharge work mat, an electrostatic monitor, and electrostatic discharge wrist bands. All computers were inspected and operated (i.e., diagnostic testing, long-term operation of computers for analysis of residual effects) on the ESD workstations. During operation of the computers, all computers were energized using surge protectors (BELKIN seven-outlet home/office surge protector with six-foot cord, Part # BE107200-06; Belkin International, Inc.; Compton, CA).

All BIs were maintained in their sterile Dupont™ Tyvek® envelopes, refrigerated, until ready for use. The BIs were allowed to come to the test temperature before being placed in the MEC test chamber. The BIs were maintained in their protective Dupont™ Tyvek® envelopes until transferred to the on-site Microbiology Laboratory for analysis.

Modified Standard Method 4500-ClO_2 E samples were kept in a dark refrigerator for one week after initial analysis for potential re-titration.

3.5 Material/Equipment Identification

Each material and piece of equipment was given an identifying code number unique to that test sample material/equipment. The codes and code sequence were explained to the laboratory personnel to prevent sample mislabeling. Proper application of the code

simplified sample tracking throughout the collection, handling, analysis, and reporting processes. All COC documentation for the test sample material/equipment was labeled with the identifying code number. Table 3-3 shows the sample coding used in this study, with Figures 3-1 through 3-8 showing pictures of all of the materials that were tested. The Category 4 equipment was labeled as DECON###, where ### refers to a three-digit sequential number. A total of 24 computers and liquid crystal display (LCD) monitors were purchased for this project. The numbers therefore ranged from 100 to 123.

Table 3-3. Sample Coding

AAA-NN-TXX-RXX			
	Sample Code	**Figure**	**Sample Type**
AAA	2AL	3-1a	3003 Aluminum coupons
	2CU	3-1b	101 Copper coupons
	2CS	3-1c	Low carbon steel coupons
	2PC	3-1d	Painted low carbon steel coupons
	2S1	3-1e	410 Stainless steel coupons
	2S3	3-1f	430 Stainless steel coupons
	2S4	3-1g	304 Stainless steel coupons
	2S6	3-1h	316 Stainless steel coupons
	2S9	3-1i	309 Stainless steel coupons
	2SW	3-2a	Stranded wires
	2LC	3-2b	DSL conditioner
	2EB	3-2c	Steel outlet/Switch box
	2SE	3-2d	Sealants (caulk)
	2GA	3-2e	Gaskets
	2DS	3-2f	Drywall screw
	2DN	3-2g	Drywall nail
	2EBC*	3-3a,b,c	Copper services
	2EBA*	3-3d,e,f	Aluminum services
	2CB	3-3g	Circuit breaker
	2SD	3-4a	Smoke detector
	2SW**	3-4b,c	Switches (lamps)
	2LP	3-5a	Laser printed colored papers (stack of 15 pages)
	2IP	3-5b	Inkjet printed colored papers (stack of 15 pages)
	2PH	3-5c	Photographs
	3PD	3-6a	PDAs
	3CE	3-6b	Cell phones
	3FA	3-6c	Fax machines (with telephones)
	3DV	3-7a	DVDs
	3CD	3-7b	CDs
	XXX	3-9	Biological Indicator (XXX=computer ID (if inside computer) or, XXX=”MEC” for inside bulk chamber)
NN	02,		Replicate number (01, 02, 03, 04,05)
TXX	T01 or T02		Test Matrix (Category 2 and 3 = T01; Category 4 = T02)
RXX	R01 – R08		Run Number (R01-R08) for Category 2 and 3 materials

* 2CS was used for low carbon steel coupons and the copper services. See Appendix B for parts list of Cu and Al service panels.
** 2SW was used for stranded wire and the switches; also 2HW was deleted as a separate category (housing wiring insulation) because 2HW was on the outside of the three-piece stranded wire (2SW).

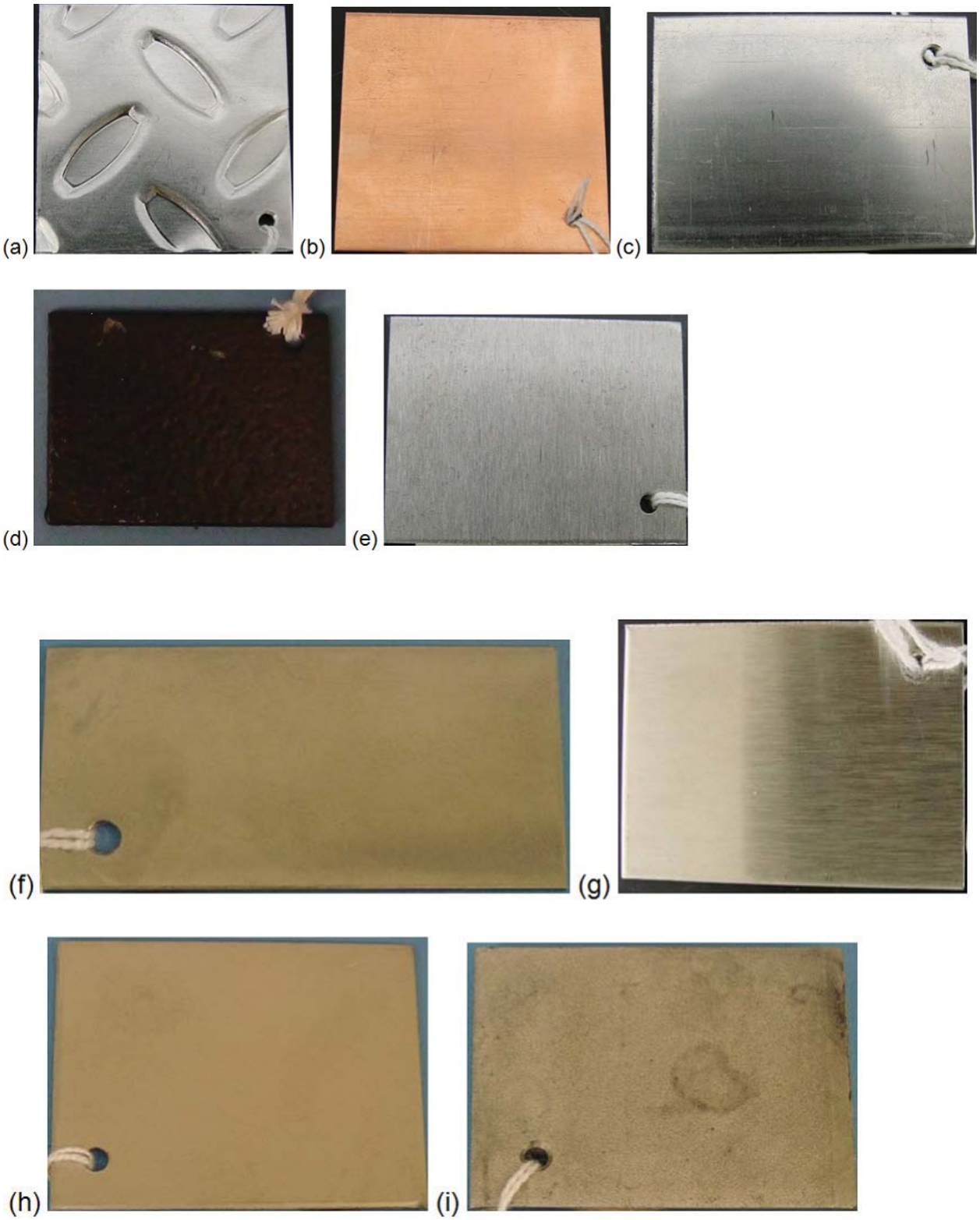
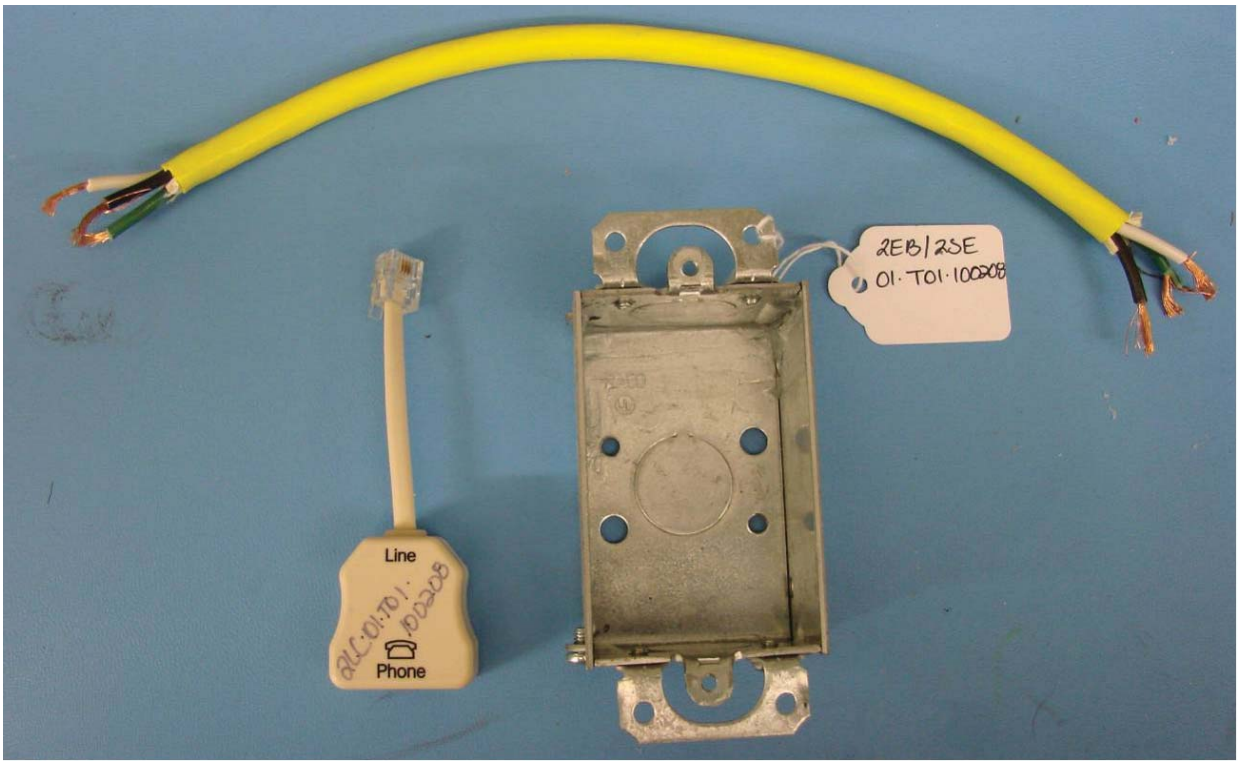
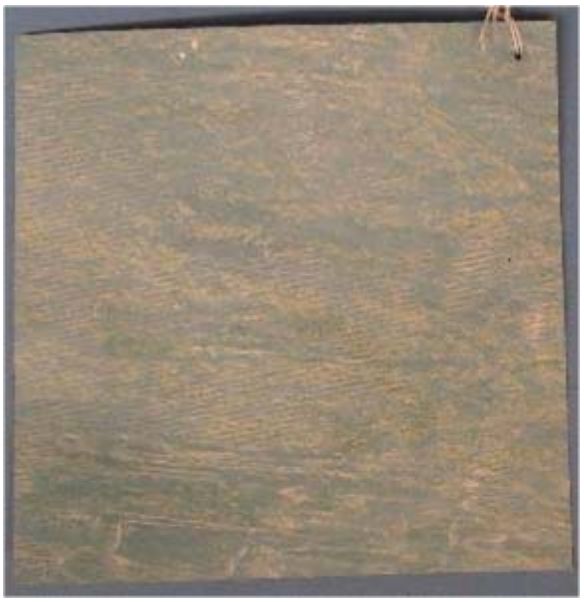


Figure 3-1. Metal coupons used in the compatibility testing (photos prior to fumigation): (a) 3003 aluminum; (b) 101 copper; (c) low carbon steel; (d) painted low carbon steel; (e) 410 stainless steel; (f) 430 stainless steel; (g) 304 stainless steel; (h) 316 stainless steel; and (i) 309 stainless steel.

(a)



(b)



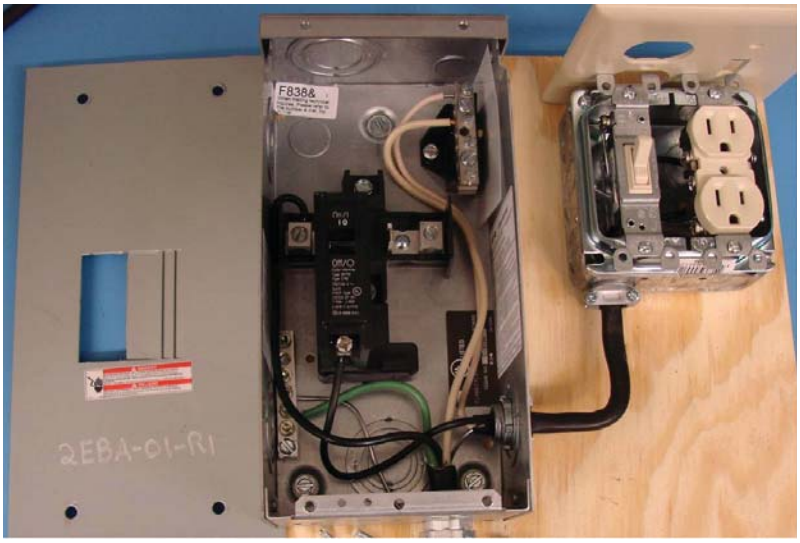
(c)

Figure 3-2. (a) Stranded wire, DSL conditioner, and steel outlet/switch box with sealant (caulk), (b) gasket and (c) drywall screws and nails used in the compatibility testing.

(a)

(b)

(c)



(d)

Figure 3-3. (a, c) Copper services, (b, d) aluminum services, and (e) circuit breaker used in the compatibility testing.

(a)

(b)

(c)

Figure 3-4. (a) Smoke detector and (b, c) lamp switch used in the compatibility testing.

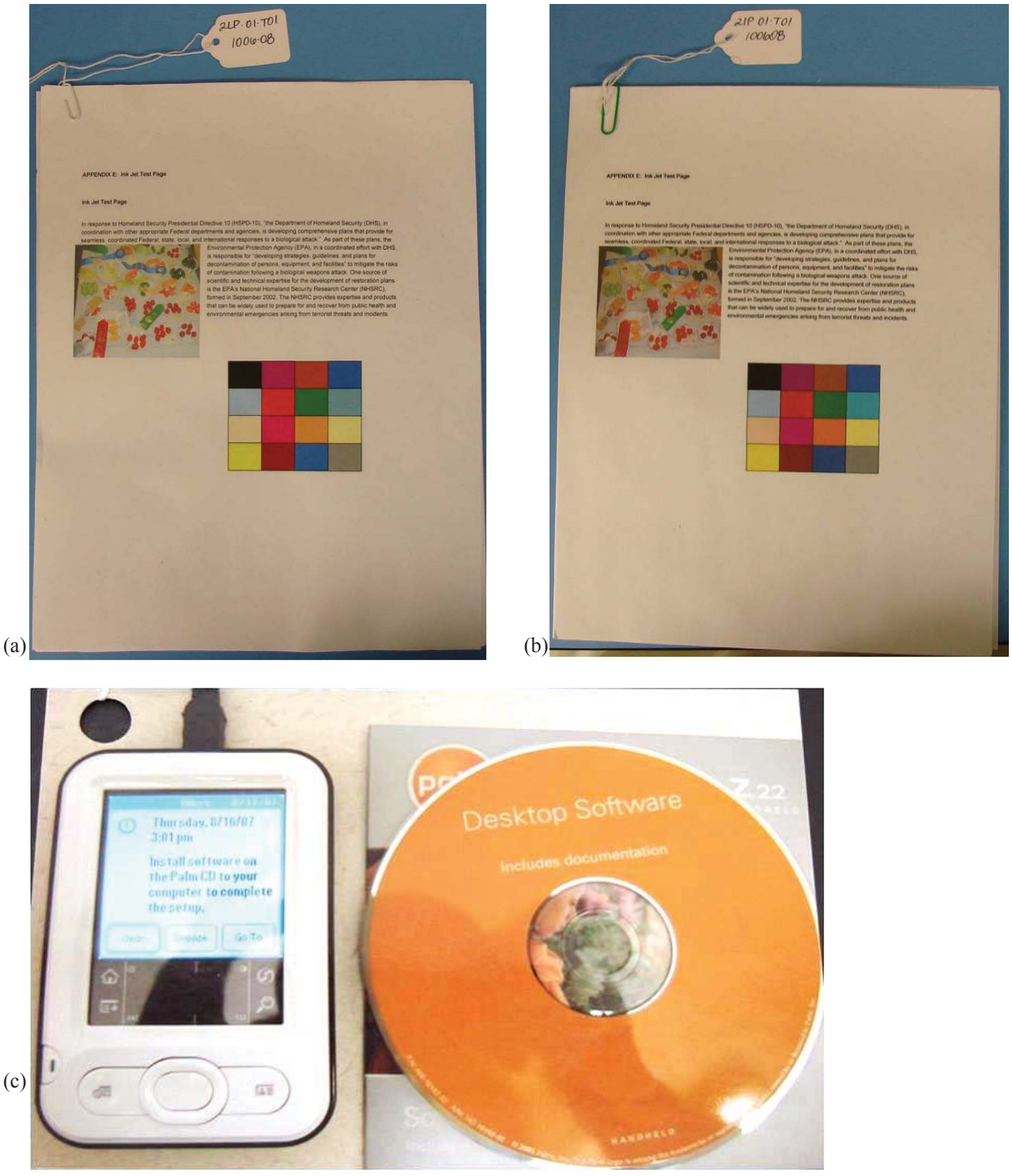
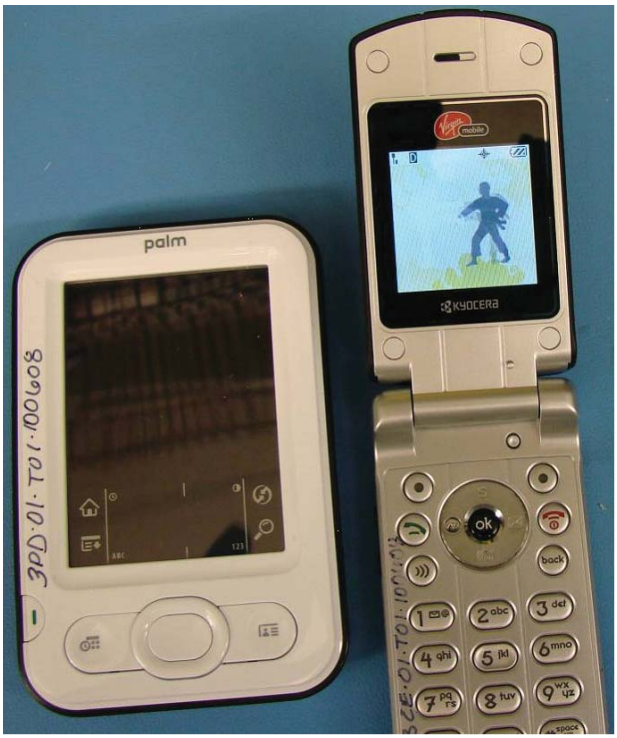


Figure 3-5. (a) Laser and (b) inkjet-printed color papers, and (c) photograph used in the compatibility testing.

(a) 

(b) 

(c) 

Figure 3-6. (a) PDA, (b) cell phone, and (c) fax machine used in the compatibility testing.

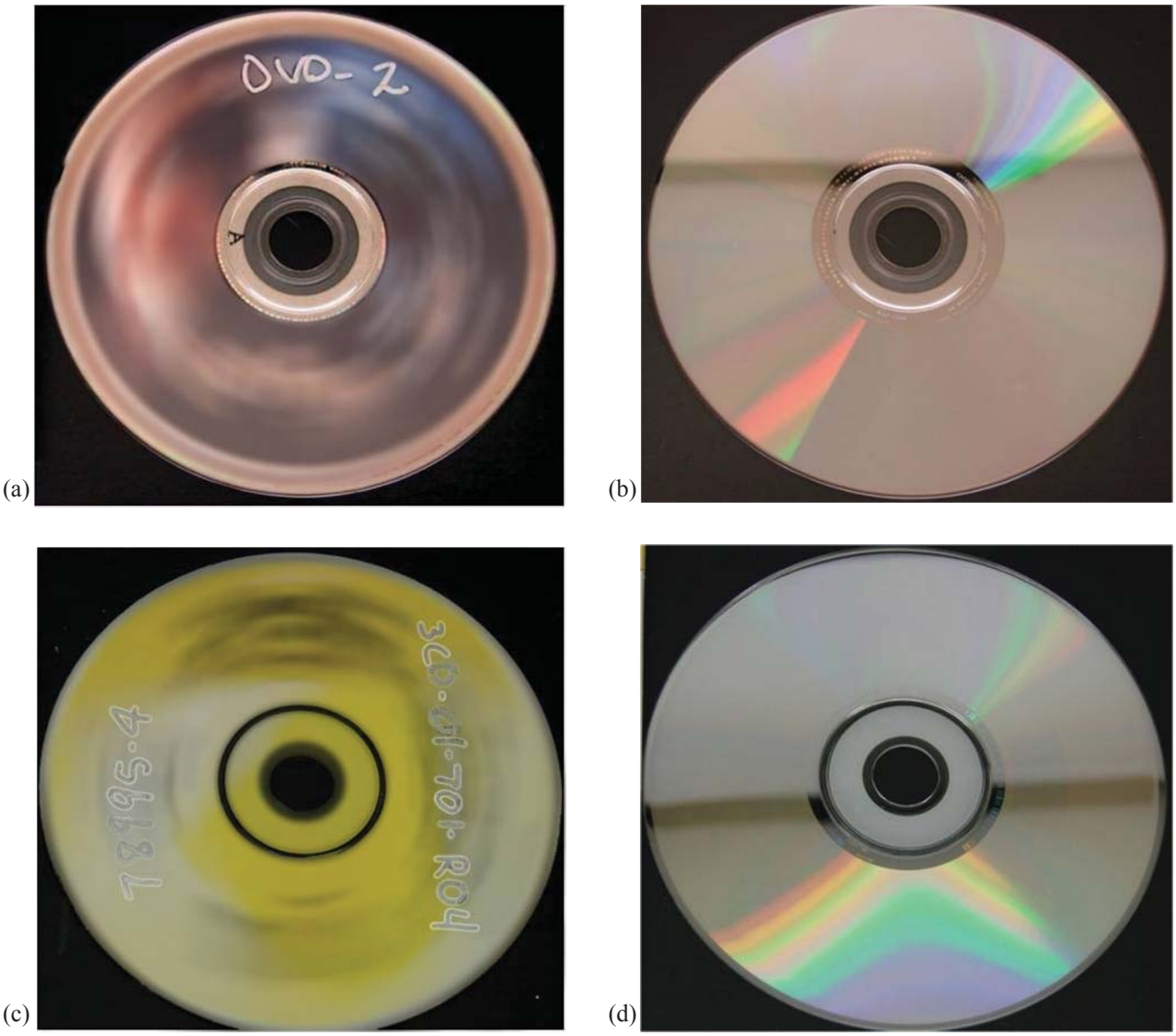


Figure 3-7. (a) Front of DVD (b) back of DVD (c) front of CD, and (d) back of CD used in the compatibility testing.

(a)

(b)

(c)

(d)

Figure 3-8. (a) Desktop computer and monitor, (b) keyboard, (c) power cord, and (d) mouse used in the compatibility testing.

3.6 Sample Shipping Procedures

The computer, monitor, and ancillary equipment shipped to Alcatel-Lucent were packaged inside Corrosion Intercept Technology bags (http://www.staticintercept.com/index.htm). The bagged equipment was shipped to Alcatel-Lucent using the original packaging (i.e., boxes and foam) after post-fumigation tests. The shipping and handling protocols were provided by Alcatel-Lucent.

3.7 Chain of Custody

- Each material/piece of equipment sent to Alcatel-Lucent had a COC record describing the material/equipment and analysis to be performed. Similarly, all the BI samples sent for analysis by the On-site Microbiology Laboratory had a COC. Examples of the COC forms for the transfer of the BI samples to the Microbiology Laboratory and the Category 4 equipment to Alcatel-Lucent are provided in Appendix B of the EPA QAPP entitled, "Compatibility of Material and Electronic Equipment during Fumigation," dated September 2008.[22]

3.8 Test Conditions

Two test matrices were used for the testing. Test Matrix T01 (Table 3-4) was used for Category 2 and 3 materials (combined), and Test Matrix T02 (Table 3-5) was used for Category 4 materials. The test matrices were built around the main objective of this project: to assess the damages, if any, to materials and electronic equipment functionality after remediation of a contaminated space using the H_2O_2 or ClO_2 technology under various fumigation environment scenarios and equipment states of operation. The list of parameters that were investigated is:

- Effect of fumigation with BioQuell HPV with 35% starting RH under conditions determined during the method development trial performed prior to this test matrix.

- Effect of fumigation with BioQuell HPV with 65% starting RH under conditions determined during the method development trial performed prior to this test matrix (***Category 2 and 3 only***).
- Effect of fumigation with BioQuell HPV with 10% starting RH under conditions determined during the method development trial performed prior to this test matrix (***Category 2 and 3 only***).
- Effect of fumigation with BioQuell HPV with 35% starting RH under conditions determined during the method development trial performed prior to this test matrix with 1.5x duration (***Category 2 and 3 only***).
- Effect of fumigation with STERIS 1000ED at 250 ppm H_2O_2 concentration with initial RH of 35% with a total CT of 1000 ppm-hr .
- Effect of fumigation with STERIS 1000ED at 250 ppm H_2O_2 concentration with initial RH of 35% with a total CT of 250 ppm-hr (***Category 2 and 3 only***).
- Effect of fumigation at high ClO_2 concentration (3000 ppmv) at standard conditions (75% RH, 75 °F) with a total CT of 9000 ppmv-hr (***Category 4 only***).
- Effect of fumigation at field demonstration ClO_2 concentration (750 ppmv) at standard conditions (75% RH, 75 °F) with a total CT of 9000 ppmv-hr (***Category 4 only***).
- Power state of Category 4 materials during BioQuell HPV and STERIS 1000ED fumigations.

Table 3-4. Test Conditions for Category 2 and 3 Materials

Run Name	Treatment Conditions and Equipment Power State[a]	Purpose of Test
R01	*BioQuell HPV fumigation with starting RH of 35%:* 326 ppmv H_2O_2 76% RH 31 °C 1 hours ON	Determine the effect of initial RH on HPV fumigation conditions.
R02	*BioQuell HPV fumigation with starting RH of 65%:* 203 ppmv H_2O_2 89% RH 29 °C 1 hours ON	Determine the effect of higher initial RH on HPV fumigation conditions
R03	*BioQuell HPV fumigation with starting RH of 10%:* 482 ppmv H_2O_2 95% RH 33 °C 1 hours ON	Determine the effect of low initial RH on HPV fumigation conditions.
R04	*BioQuell HPV fumigation with starting RH of 35% with 1.5x duration:* 335 ppmv H_2O_2 87% RH 31 °C 1 ½ hours ON	Determine the effect of initial RH on HPV fumigation conditions for longer dwell time
R05	*STERIS VHP fumigation at 250 ppm, 1 hours (CT = 250 ppm-hr):* 246 ppmv H_2O_2 27% RH 28 °C 1 hour ON	Determine the effect of low H_2O_2 CT.
R06	*STERIS VHP fumigation at 250 ppm, 4 hours (CT = 1000 ppm-hr):* 257 ppmv H_2O_2 40% RH 28 °C 4 hours ON	Determine the effect of high H_2O_2 CT.

[a] Dwell phase parameters are listed for each run's Test Condition.

Table 3-5. Test Conditions for Category 4 Equipment

Test Condition or Run Name	Subset Run Name or Computer Label	Treatment Conditions and Equipment Power State	Purpose of Test
1	Decon 106-108	Control (no fumigation) ON and Active	Control test set.
2	Decon 118,119,123	Standard fumigation conditions (3000 ppmv ClO_2, 75% RH, 75 °F, 3 hrs) ON and Active	Effect of standard fumigation conditions on equipment when computers are operational.
3	Decon 120-122	Standard fumigation conditions (3000 ppmv ClO_2, 75% RH, 75 °F, 3 hrs) ON and Idle	Tie in to past matrix with ClO_2
4	Decon 115-117	Field demonstration fumigation conditions (750 ppmv ClO_2, 75% RH, 75 °F, 12 hrs) ON and Idle	Effect of fumigation conditions used during field demonstrations for *B. anthracis* remediation
5	Decon 103-105	BioQuell HPV fumigation with starting RH of 35% OFF	Effect of power state
6	Decon 100-102	BioQuell HPV fumigation with starting RH of 35% ON and Active	Effect of power state
7	Decon 112-114	STERIS VHP fumigation at 250 ppm, 4 hours (CT = 1000 ppm-hr), OFF	Effect of power state
8	Decon 109-111	STERIS VHP fumigation at 250 ppm, 4 hours (CT = 1000 ppm-hr) ON and Active	Effect of power state

Note: 75 °F = 23.9 °C

4.0
Visual Inspection

Photographs were taken as part of the scheduled functionality testing. The purpose of this physical documentation was to make comparisons over time, looking for changes such as discoloration of wire insulation, corrosion, residue, and decrease in the quality or readability of documents and photographs. Where changes were noted, all visual files and written documentation were reviewed to provide a detailed understanding of the effects of fumigation over time on that material/component. Functional effects are presented and discussed in Section 5.

4.1 Category 2 Materials

Category 2 materials maintained their pre-exposure physical and functional characteristics throughout the 12 month observation period following both BioQuell HPV and STERIS VHP fumigations.

- Four runs were conducted using BioQuell HPV (Runs R01 through R04 in Table 3-4) to determine the effects of varying the initial RH (10%, 35% and 65%) as well as extending the duration of the fumigation (1.5x). Regardless of the initial RH or fumigation duration, the Category 2 materials showed no signs of physical deterioration during the 12 month post-test observation period.
- Two runs were conducted using STERIS VHP (Runs R05 and R06 in Table 3-4) to determine the effects of both low (250 ppm-hr) and high (1000 ppm-hr) H_2O_2 concentration exposures. During the 12 month post-exposure observation period, no physical changes to any of the Category 2 materials were noted.

Figure 4-1 shows the original Inkjet printed paper (a) before and (b) one year after being exposed to BioQuell HPV fumigation with a starting RH of 35% (test run R01). Similar photos are shown for laser printed paper (c) before and (d) one year after, and color printed photographs (e) before and (f) one year after BioQuell HPV fumigation with a higher starting RH of 65% (test run R02).

These results are typical for all six fumigation conditions studied with both BioQuell HPV and STERIS VHP fumigation technologies. The printed paper and photographs for each fumigation condition remained visibly unchanged throughout the 12-month post fumigation observation period. Color pigments do not appear to be adversely affected by exposure to vaporized H_2O_2 at either high or low concentrations or RH levels. In addition, extending the duration of the H_2O_2 exposure by 1.5x (test run R04) had no impact on these Category 2 materials.

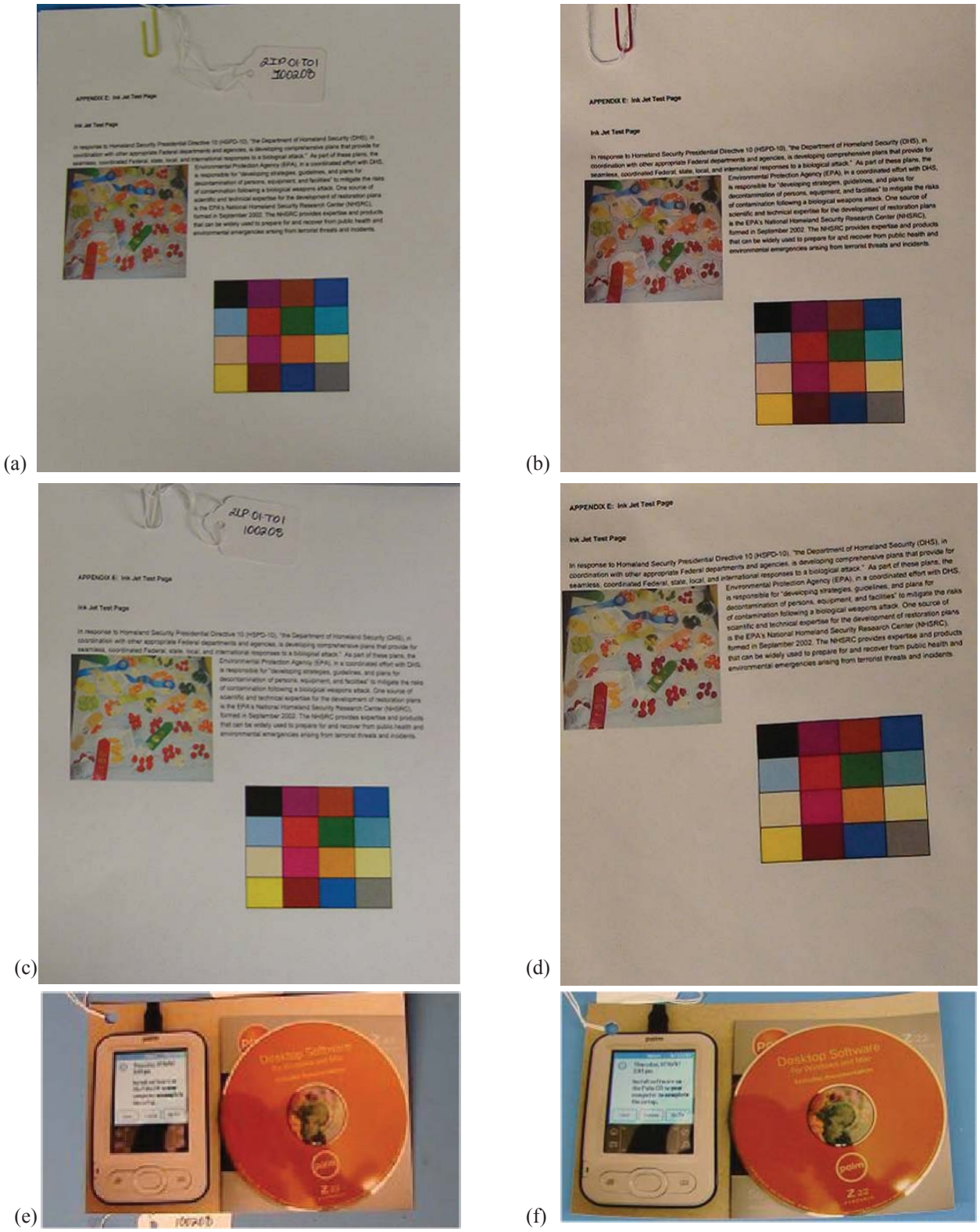
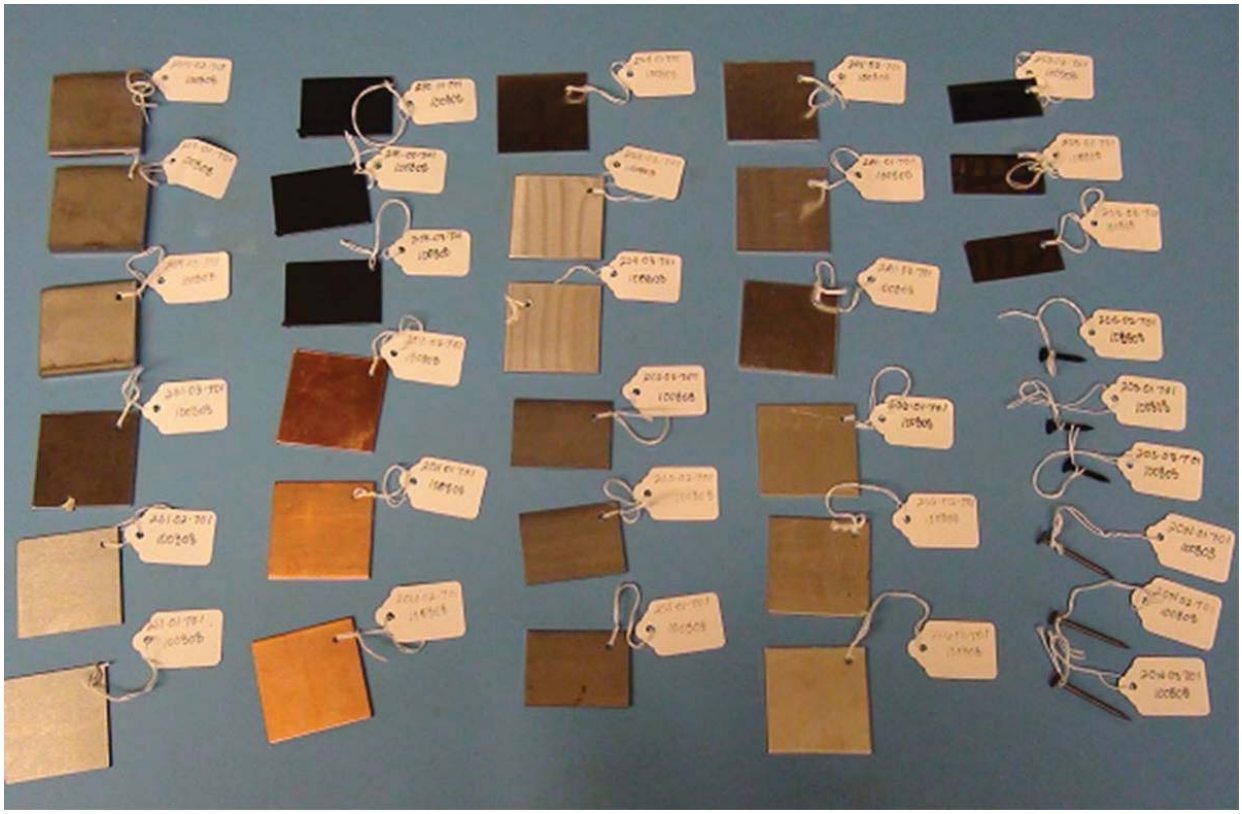


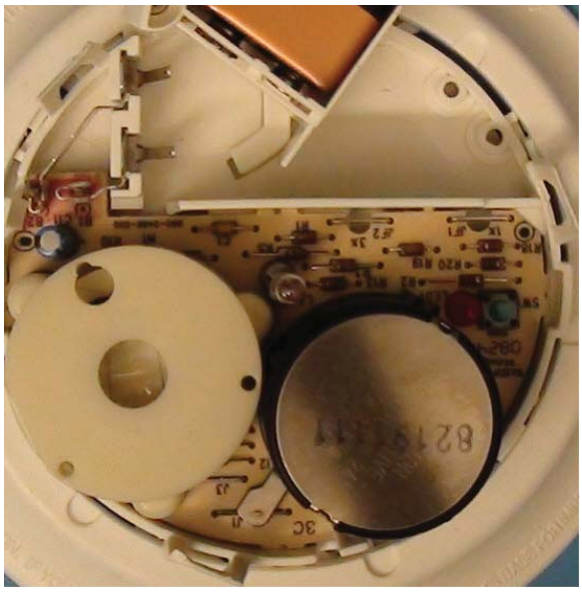
Figure 4-1. Inkjet printed paper (a) before and (b) 12 months after HPV fumigation (R01). Laser printed paper (c) before and (d) 12 months after HPV fumigation at higher initial RH (R02). Glossy 5”x 6” color photographs (e) before and (f) 12 months after HPV fumigation at higher initial RH (R02).

Vaporized H_2O_2 exposure showed no caustic effects on the other Category 2 materials tested under any of the test conditions. Figure 4-2(a) shows that each set of metals remained tarnish free, with no signs of rust or corrosion. Each exposed smoke detector remained fully operational throughout the year after exposure; the battery terminals, resistors, and other components showed no signs of physical damage as seen in Figure 4-2 (b). Figure 4-2 (c) shows that the exposed stranded wires remained tarnish free for 12 months after exposure. These results were typical for each of the six fumigation conditions.

(a)



(b)



(c)

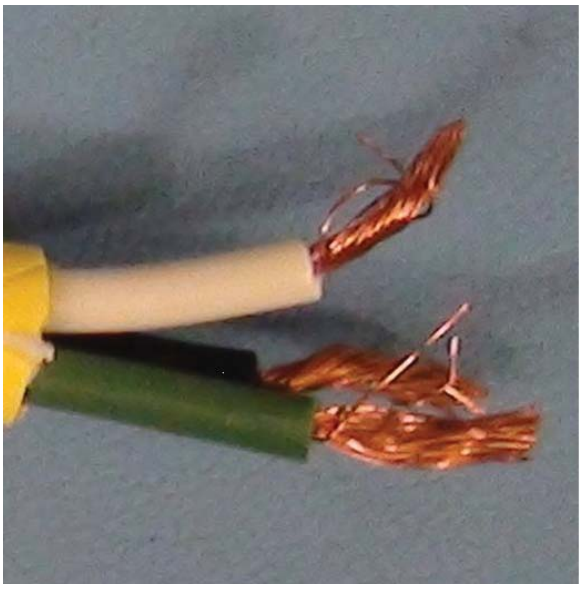


Figure 4-2. (a) Category 2 metals, (b) Inside of a smoke detector, and (c) exposed wire of stranded wire 12 months after H_2O_2 fumigation.

The results of this study indicate that there were no physical or functional effects on any of the Category 2 materials tested following H_2O_2 exposure. These conditions included varying the initial RH, as well as the H_2O_2 concentrations and exposure duration. The Category 2 materials were shown to be compatible from a visual standpoint with both the BioQuell HPV and STERIS VHP fumigations performed in this study.

4.2 Category 3 Materials

Category 3 Materials included small, personal electronic equipment: fax machines, cell phones, PDAs, CDs, and DVDs. The physical appearance of these materials was observed and photo-documented before fumigation and during the one year observation period following HPV fumigation.

The CDs and DVDs were all apparently unaffected by H_2O_2 exposure. The disks maintained their pre-exposure appearance and showed no signs of damage during the 12 month observation period. Figure 4-3 shows the internal features of a representative fax machine. There were no signs of damage to any of the mechanical parts and all exposed metal maintained pretest appearances and showed no signs of deterioration.

Figure 4-3. Internal view of fax machine 12 months after HPV exposure.

Figure 4-4 shows the cell phones, powered on, one year following HPV fumigation. During the 12-month observation period, no visual changes were noted. None of the cell phone screens indicated any signs of dimming of the back light or detectable color alterations.

With the exception of the PDA from test run R05, Figure 4-5 shows that the screens from the remaining PDAs maintained their pre-exposure physical appearance. The R05 PDA failed to power on, and an examination of the screen appearance could not be performed. The outer casing of all PDAs appeared unchanged. An internal physical evaluation of the PDAs was not possible without damaging the device.

Figure 4-4. Cell phones powered on 12 months after exposure.

Figure 4-5. PDAs powered on 12 months after exposure.

The PDA that would not power on (R05) was the low concentration STERIS VHP run (250 ppm-hr CT). The high concentration STERIS VHP run (test run R06 at 1000 ppm-hr CT, shown in the bottom right of Figure 4-5) powered on normally and had no indication of change in the screen's physical appearance. This observation indicates that the failure of R05 may not be related to the HPV exposure, but that R05 was a flawed PDA that would have failed under normal use. Because this failure to power on was the only effect seen in any of these items, these results indicate that Category 3 materials are compatible from a visual impact standpoint with both the BioQuell HPV and STERIS VHP fumigations performed in this study.

4.3 Category 4 Equipment

Category 4 equipment included desktop computers and monitors. Unlike the Category 2 and 3 materials that were fumigated only with H_2O_2, the Category 4 materials were also exposed to ClO_2. Table 4-1 summarizes the visual changes noted for both fumigants.

Table 4-1. Documented Visual Changes in Category 4 Equipment

Equipment	Visual Changes Due to ClO_2 Exposure	Visual Changes Due to H_2O_2 Exposure
Desktop computer	Corrosion (inside and outside) and powdery residue	None
Computer monitor	One monitor turned green (at 750 ppmv, 12-hour exposure)	None
Computer keyboard	None	None
Computer power cord	None	None
Computer mouse	None	None

The ClO_2 fumigation conditions exhibited showed some visually observed effects on the desktop computers (corrosion inside and outside and powdery residue). The only other visual change noted for any of the other computer components was that one of the computer monitors from the 750 ppmv ClO_2 fumigation experienced discoloration (turned green). The other two monitors from this test could not be visually checked, as they stopped functioning several months into the year-long observation period. These changes resulting from ClO_2 exposure agree with previous research conducted on this fumigant[5].

No visual changes were noted for any Category 4 equipment that had been exposed to H_2O_2, regardless of concentration and run conditions. A summary of the noted visual changes related to run conditions is shown in Table 4-2. Any changes observed were present immediately after fumigation and did not appear to strengthen over the 12-month period of equipment observation and testing.

Table 4-2. Summary of Visual Changes Noted in Category 4 Equipment

Fumigant	ClO_2	ClO_2	ClO_2	BioQuell HPV	BioQuell HPV	STERIS VHP	STERIS VHP®
Temp, °C	26.1	26.1	26.3	30.7	30.6	30.2	28.7
RH, %	75	75	79	90	95	31	33
ppmv	3000	3000	750	278	357	252	246
ppmv-hours	N/A	N/A	N/A	308.4	444.9	1067	1049
Computer Status	118, 119, 123 On and Active	120-122 On and Idle	115-117 On and Idle	103-105 OFF	100-102 On and Active	112-114 OFF	109-111 On and Active
Desktop Computer	Internal and external corrosion Internal powdery residue	Internal and external corrosion Internal powdery residue	Internal and external corrosion Internal powdery residue	No changes	No changes	No changes	No changes
Computer monitor	No changes	No changes	One monitor turned green	No changes	No changes	No changes	No changes

N/A – data not available

Corrosion of external metal parts was evident on the backs of most of the computers exposed to ClO_2. In addition, although the CT was 9000 ppmv-hr for all three ClO_2 fumigation scenarios, the longer duration (12 hours) of the 750 ppmv fumigation resulted in more serious corrosion.

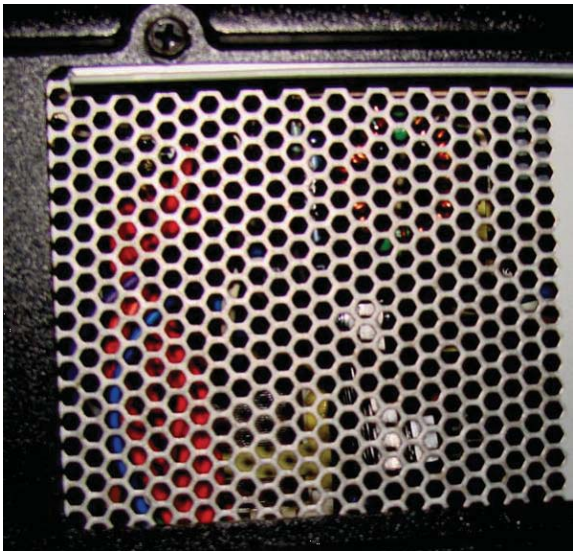
Figure 4-6(a) shows very little corrosion on the top metal grid of the 3000 ppmv ClO_2-fumigated computers. Whether the computers were active or idle appeared to make no difference, and this picture is representative of what was seen. However, Figure 4-6(b) shows noticeable corrosion on the same grid at 750 ppmv ClO_2.

Corrosion was also observed on the central grid on the backs of computers. This corrosion took the form of a white powder as can be seen in Figure 4-7(b). This white powder was seen in all computers which underwent fumigation with ClO_2. The grid from one of the 750 ppmv fumigations is shown here; the powder was less visible in the 3000 ppmv fumigations (whether active or idle).

Rust-like powder was frequently seen on the PCI slot covers on the lower rear of the ClO_2 exposed computers, as shown in Figure 4-8. The corrosion was similar for all ClO_2 fumigations, but was of less severity in the 3000-ppmv exposed computers (a) than in the 750 ppmv, 12-hour exposures (b and c).

Figure 4-9 shows an unexposed power supply case grid (a) and similar corrosion found on computer grids exposed to (b) 3000 ppmv and (c) 750 ppmv ClO_2. Again, more extensive corrosion is evident in the longer 750 ppmv exposed computer. For the 3000 ppmv exposed computers, the grids appeared similar, whether they were active or idle during the fumigation.

(a)



(b)

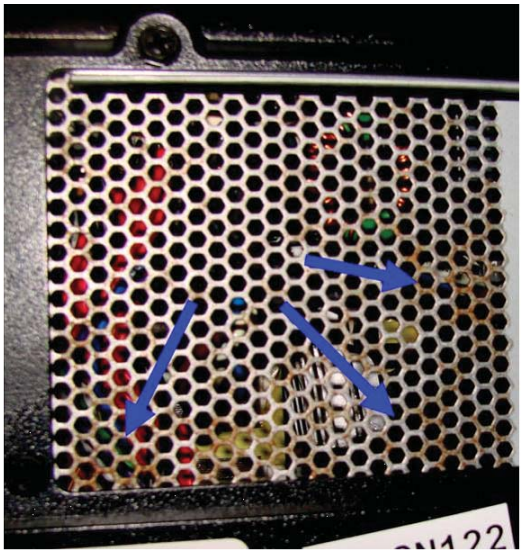
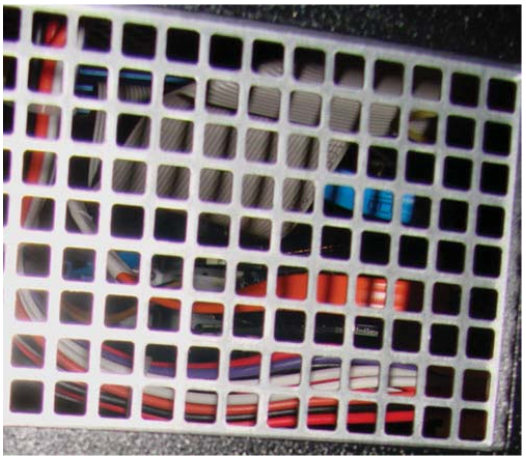


Figure 4-6. Comparison of the top metal grid on the back of tested computers. The computer in (a) was fumigated at 3000 ppmv for 3 hours and shows little corrosion. Computer (b) was fumigated at 750 ppmv for 12 hours. Blue arrows indicate selected areas of significant corrosion.

(a)



(b)

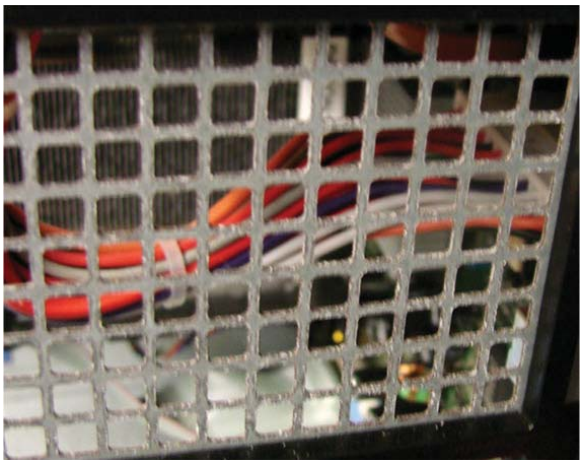


Figure 4-7. Central grid on the backs of computers not exposed (a) and exposed (b) to 750 ppmv ClO_2. The corrosion is visible as a white powdery crust along the edges of the holes in the grid.

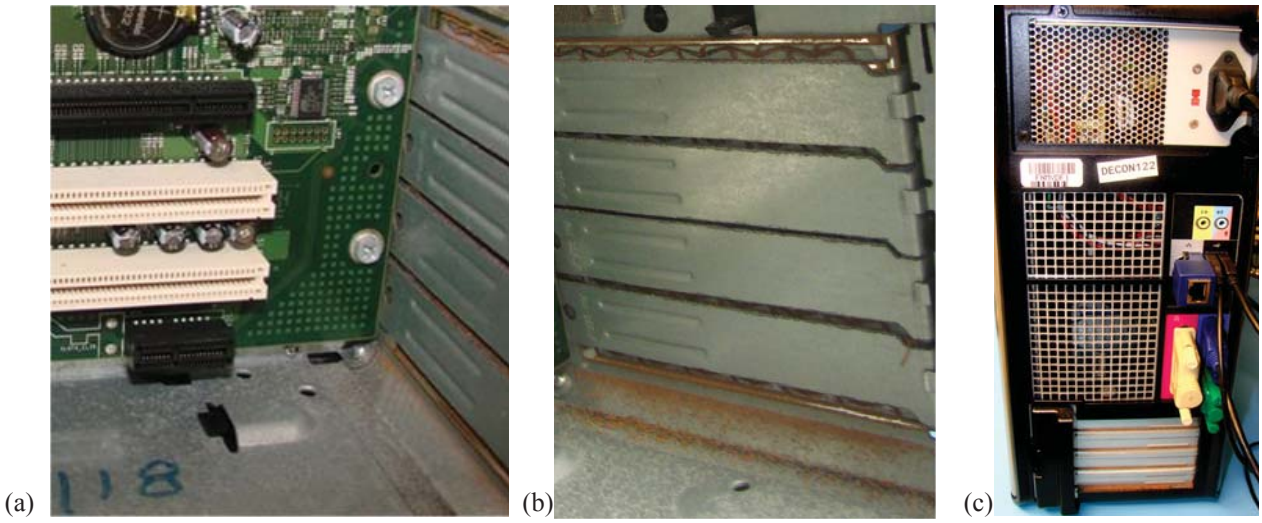


Figure 4-8. Corrosion of PCI slot covers exposed to ClO_2 in (a) 3000 ppmv and (b) 750 ppmv fumigations. Also evident in (c) is corrosion of the metal grids covering the back of the computer.

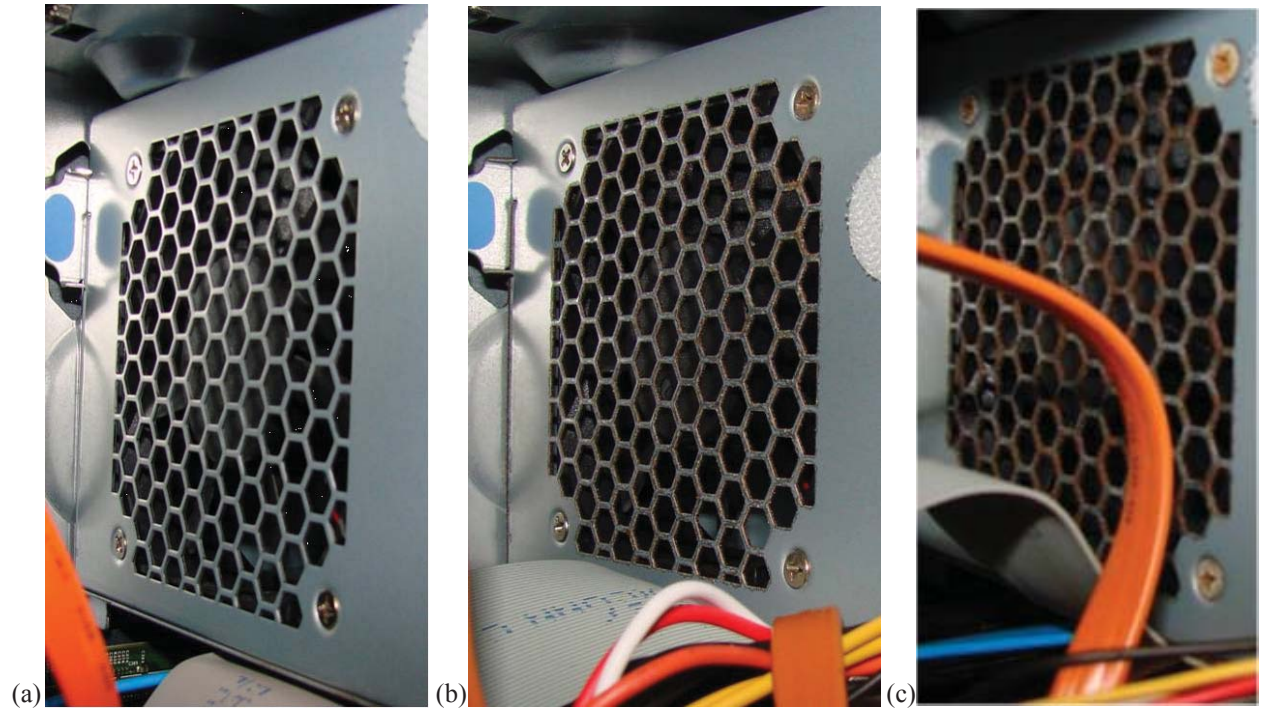


Figure 4-9. An unexposed power supply case with no corrosion (a) compared to a corroded grid seen on computers fumigated with ClO_2 at (b) 3000 ppmv and (c) 750 ppmv.

Other corrosion was evident, in the form of a white powder, on the central processing unit (CPU) heat sink in ClO_2 exposed computers. Figure 4-10 shows the range of corrosion seen on the CPU heat sink as compared to an unaffected heat sink (a). Figure 4-10(b) shows much less corrosion in a 3000 ppmv computer that was ON and active, as opposed to the 3000 ppmv computer that was powered ON and idle (c). The most widespread and serious corrosion was seen on the 750 ppmv computer (d) that was On and idle, and exposed to ClO_2 for 12 hours.

Most, if not all, of the corrosion in the ClO_2 exposed computers appears to be originating on the CPU heat sink. When computers were ON and active, the fan helped blow the dust off the CPU itself. Figures 4-10(b) and (c) clearly show the difference between computers that were active (b) versus idle (c).

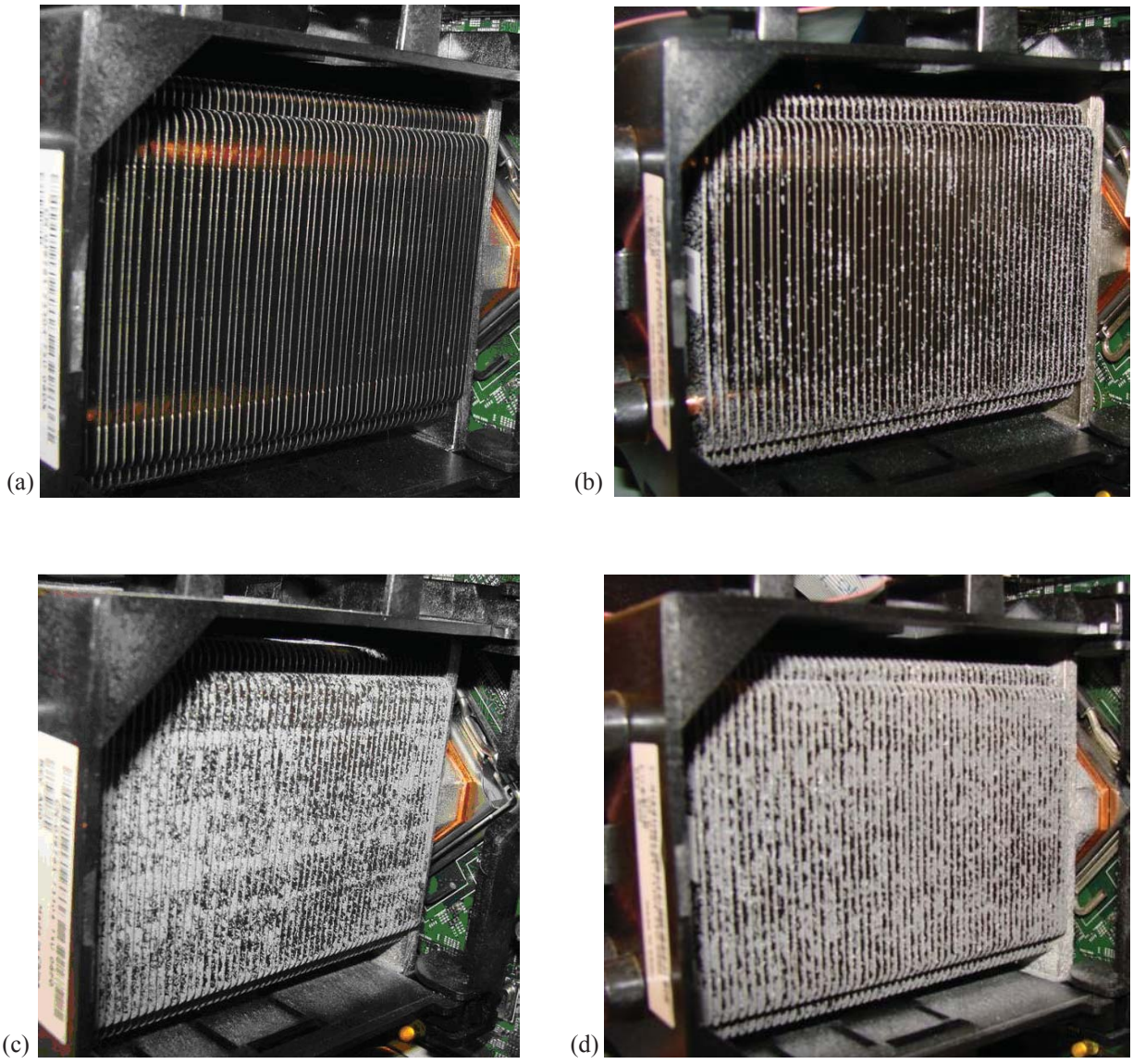


Figure 4-10. (a) A computer CPU heat sink not exposed to ClO_2. Moderate corrosion on 3000 ppmv computer that was ON and active (b), compared to severe corrosion seen when ON and idle (c). Widespread, severe corrosion on the 750 ppmv exposed computer (d).

Figure 4-11 shows one significant internal item of note: the graphics processing unit (GPU) heat sink remained unaffected in the same computers that demonstrated corrosion of the CPU heat sink. This observation matches previous research results of exposure to chlorine dioxide[17] and was discussed by Alcatel-Lucent[15] in their CBRTA report as being due to the different metallic compositions of the two heat sinks. The CPU heat sink consists of an aluminum alloy with a nickel-phosphorus coating which can experience galvanic corrosion, while the GPU heat sink is simply a single aluminum alloy.

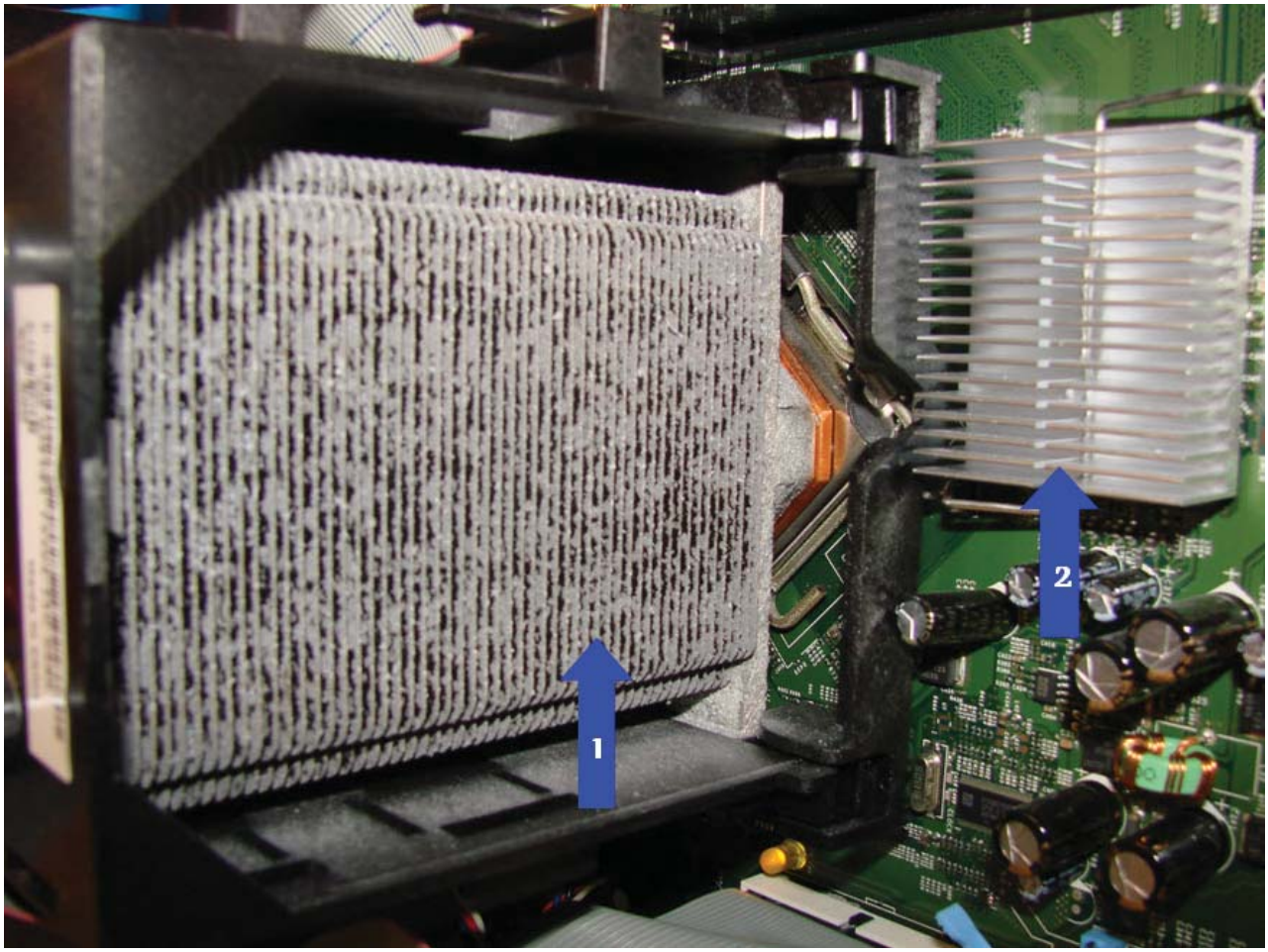


Figure 4-11. Computer heat sinks after exposure to ClO_2. Arrow 1 points to the CPU heat sink, which displays significant corrosion, while the GPU heat sink, indicated by Arrow 2, shows none.

The powder covering the CPU heat sink was one of several types observed within the computer casing of all computers after ClO_2 fumigation. Figure 4-12 clearly shows at least two of the distinct powder types found (one white and one brown). Prior analysis by Alcatel-Lucent identified four prevalent types of corrosion particles present following ClO_2 fumigation. These particles contained aluminum and chlorine, aluminum and nickel, iron, or nickel, each combined with oxygen, carbon, and other elements. These particles are discussed in further detail in the Alcatel-Lucent CBRTA report.[16]

Because the PC-Doctor® testing protocol required opening the computer chassis, the dust inside the computer chassis presented a safety hazard to operators. The computers were placed on an anti-static mat within a hood and vacuumed during monthly PC-Doctor® tests. The cleaning operation may have improved the operation of the computers by removing hygroscopic particles that could have conducted or shorted any electrical components within the chassis.

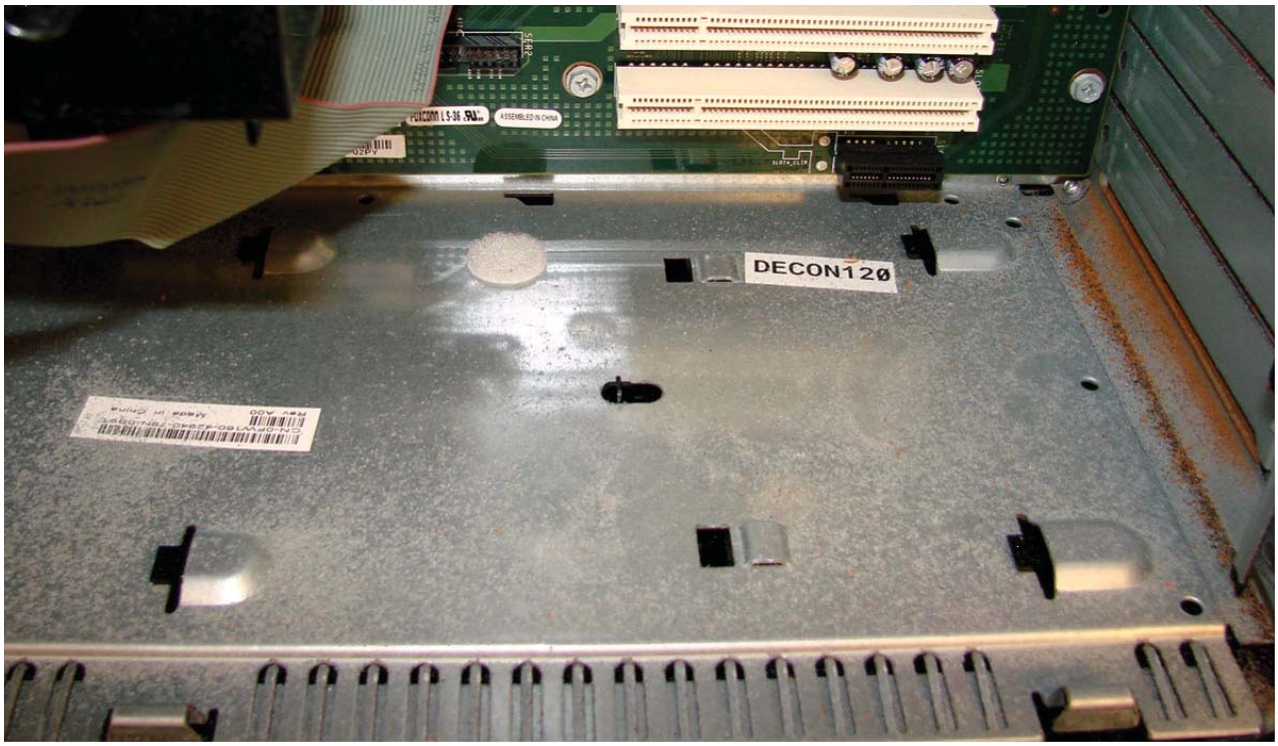


Figure 4-12. Inside bottom of computer case exposed to ClO_2 showing two distinct powders produced by corrosion. White powder can be seen throughout the bottom, while rust-colored powder is seen primarily at the rear of the case (along right edge in this figure).

In summary, no visible changes were recorded for any Category 4 equipment that was exposed to either BioQuell HPV or STERIS VHP fumigation technologies, regardless of power state of the computers. However, significant visible changes occurred to these same computers that were exposed to ClO_2 fumigation. These changes included external and internal corrosion of metal parts and the formation of powders inside the computer casing. Also, one of the computer monitors experienced discoloration (turned green).

Parts affected by the ClO_2 fumigations included external and internal stamped metal grids, external metal slot covers, and the internal CPU heat sink. Internal corrosion was more severe for the 3000 ppmv computers that were powered ON but were idle, versus those that were powered ON and were active. However, the most severe and widespread corrosion was seen on the 12-hour, 750 ppmv ClO_2 fumigated computers (also ON and idle). Although all computers had a CT of 9000 ppmv-hr, the longer duration of the 750 ppmv exposure appears to have contributed to the more significant corrosion seen.

Most, if not all, of the corrosion-generated powder may be coming from the CPU. When the computers were powered ON and were active, corrosion-generated powder was blown off the CPU.

5.0
Data/Analysis/Functionality Tests

The results of functionality tests were reviewed for each material pre-exposure, immediately post-exposure, and then up to monthly thereafter for a period of one year looking for instances of intermittent or repeated failures. These tests ranged from simple stress tests performed on gaskets to the highly detailed PC-Doctor® Service Center™ 6 testing conducted on the Category 4 computers. Where changes were noted, all visual files and written documentation were reviewed to provide a detailed understanding of the effects of fumigation and the different run conditions on that material/component. For the Category 4 computers, failures are identified by the component parts themselves (such as CD and DVD drives) as well as the sub-component parts that are most likely to lead to failure of that component.

5.1 Category 2 Materials

Functionality tests were performed on Category 2 materials before and after H_2O_2 treatment, then periodically after exposure, and again at year's end. The breakers used in the Cu and Al services were the same 10 amp breakers that were tested alone. Because of the large number of breakers requiring testing, the breakers (10 per run condition) and services were tested at 20 amps (or 200 percent). The minimum to maximum time range to failure under these conditions is from 10 to 100 seconds. None of the beakers or services from any test fell outside the acceptable testing range. The resistance measurements over 1 year have an average standard deviation of 36 percent and range between 0 and 4.1 ohms. No functionality changes were reported for any Category 2 materials exposed to either the BioQuell or STERIS H_2O_2 technologies.

5.2 Category 3 Materials

Functionality tests were performed on Category 3 materials before and after H_2O_2 treatment, monthly for five months and then again at the one-year period. Category 3 materials consisted of PDAs, cell phones, fax machines, CDs, and DVDs. The results from these functionality tests show that no changes occurred during the one year observation period, with the exception of one of the PDAs.

All six PDAs remained in their original working condition with the exception of the PDA from test run R05 (the low concentration STERIS VHP®, 250 ppm-hr CT). All functioning PDAs were able to synchronize with software installed on a desktop computer. The touch screen capability was not compromised for any of the working PDAs.

The malfunctioning R05 PDA failed to power on at month 12 following the H_2O_2 fumigation. An internal physical evaluation of the PDAs was not possible without damaging the device, but the R05 PDA battery was unable to take a charge. The PDA may not have been functional due to a bad battery or as the result of damaging effects of the Test Condition 6 fumigation. However, since all electronic equipment other than R05 showed no signs of physical or functional damage, nor did any of the electronic equipment from R06 (high concentration STERIS VHP®, 1000 ppm-hr CT) show physical or functional damage, the failure of R05 was probably not related to the HPV exposure, but due to a flawed PDA that would have failed under normal use.

There was no evidence that vaporized H_2O_2 had any harmful effects on the operation of the cell phones. The cell phones from each condition were able to send and receive calls, provide clear audio on both ends of the call, and maintain the same clear ringtone for incoming calls as they had done prior to exposure. The keypads for each phone remained fully operational. The batteries maintained their capability to charge fully and showed no physical signs of damage.

The fax machines from each test condition maintained the same level of operation throughout the year.

The quality of the facsimiles was comparable at year end to the quality of the facsimiles before exposure. The telephone component of the fax machines also remained in good working condition.

The same computer was used to test the CDs and DVDs before and during the 12-month observation period following exposure. No problems were encountered reading the disks at any time. The sound quality of the CDs after exposure was comparable to the sound quality before exposure. Similarly, the sound and picture quality of the DVDs showed no signs of degradation, however a byte level comparison of the media before and after exposure was not performed..

5.3 Category 4 Equipment

PC-Doctor® Service Center™ 6 is commercially available software designed to diagnose and detect computer component failures. While the exact number and type of

tests depend on the system being tested (see Appendix C), for the case of the Category 4 equipment, a total of 172 tests were run. Some tests were not compatible with Dell™ basic input/output system (BIOS) under Windows and needed to be tested in the disk operating system (DOS) environment. A complete list of the PC-Doctor® Service Center™ 6 tests is shown in Appendix D.

The PC-Doctor® Service Center™ 6 protocol was developed and provided by Alcatel-Lucent for this effort. Alcatel-Lucent chose PC-Doctor® in order to have an industry-accepted standard method of determining pass versus failure of the computer subsystems. PC-Doctor® Service Center™ 6 functionality testing was conducted pre-fumigation, one day post-fumigation, then monthly for the next year, except for computers fumigated with the BioQuell method, which were not tested the first month after fumigation but were then tested monthly afterwards. This testing provided valuable information about the extent and time dependence of the degradation of these computers following the various fumigation scenarios. All computers were kept under ambient laboratory conditions.

Standard protocol called for each test to be performed once. If any particular test failed the first time, the computer was tested a second time to correct for possible human error. A test that failed the second time was labeled “Fail”. If the test failed the first time but passed the second time, it was labeled “Pass2”. There were certain instances when the computer did not allow certain tests to be run. These instances were listed as “False-Fail”, because though the test was not run, it was considered a failure since the test should have been able to run. For tabulation, a score of 1,000 was assigned to each “Fail” and “False-Fail”, while a “Pass2” received a score of 1. During each pre- and post-fumigation testing period, a total PC-Doctor® score was assigned to each computer based upon the number of tests that failed on the first or second attempt.

Table 5-1 shows this score for each month for each computer. For months and computers where tests received a “Fail”, the specific tests that failed are listed by test number for the month in adjacent columns.

Table 5-1. PC-Doctor® Tests That Failed Twice for all Computer Fumigation Scenarios (Yellow highlights = DVD-related components)

Control Conditions (No Fumigation, 40% RH)

decon 106

Day	Score	Failed Tests
-82	0	
1	0	
41	0	
75	0	
103	5000	54,55,56,57,58
133	5000	54,55,56,57,58
156	6000	47,54,55,56,57,58
190	12000	46,48,49,50,51,52,53,54,55,56,57,58
225	14000	47,48,49,50,51,52,53,54,55,56,57,58 60,61
271	13000	46,47,48,49,50,51,52,53,54,55,56,57,58
302	12001	47,48,49,50,51,52,53,54,55,56,57,58
330	6000	53,54,55,56,57,58
366	1002	58

Control Conditions (No Fumigation, 40% RH)

decon 107

Day	Score	Failed Tests
-82	0	
1	0	
41	2	
75	0	
103	0	
133	0	
156	0	
190	0	
226	0	
273	0	
330	1	
366	1	

3000 ppmv ClO_2, 75% RH, 3 hours, Computer On

decon 118

Day	Score	Failed Tests
-39	0	
1	0	
35	0	
63	0	
95	0	
162	0	
227	0	
282	0	
312	0	
346	0	
368	0	

3000 ppmv ClO_2, 75% RH, 3 hours, Computer On

decon 123

Day	Score	Failed Tests
-7	0	
1	0	
35	0	
63	1	
95	0	
128	5000	13,23,26,36,37
148	0	
177	0	
206	0	
232	1	
275	5000	59,60,61,62,63
310	5000	59,60,61,62,63
345	17	
367	1	

3000 ppmv ClO_2, 75% RH, 3 hours, Computers On

decon 120

Day	Score	Failed Tests
-31	0	
1	0	
28	0	
58	0	
86	0	
121	0	
154	0	
184	0	
213	0	
239	0	
283	0	
317	0	
352	0	

3000 ppmv ClO_2, 75% RH, 3 hours, Computers On

decon 121

Day	Score	Failed Tests
-31	0	
1	0	
29	0	
58	0	
86	0	
121	0	
154	0	
184	0	
213	0	
239	0	
282	0	
317	0	
357	1	

3000 ppmv ClO_2, 75% RH, 3 hours, Computers On

decon 122

Day	Score	Failed Tests
-32	0	
1	0	
29	2	
58	4	
86	1	
121	0	
154	0	
184	0	
213	0	
239	0	
282	0	
317	5000	59,60,61,62,63
354	1	

750 ppmv ClO_2, 75% RH, 12 hours, Computers On

decon 115	Day	Score	Failed Tests
	-95	0	
	1	8000	47,53,54,55,56,57,58,100
	29	7000	47,53,54,55,56,57,58
	57	7000	47,53,54,55,56,57,58
	81	7000	47,53,54,55,56,57,58
	109	7000	47,53,54,55,56,57,58
	141	7000	47,53,54,55,56,57,58
	172	7000	47,53,54,55,56,57,58
	212	Computer fails to boot - hard drive failure	

750 ppmv ClO_2, 75% RH, 12 hours, Computers On

decon 116	Day	Score	Failed Tests
	-95	0	
	1	10004	47,53,54,55,56,57,58,75,76,77
	29	10001	47,53,54,55,56,57,58,75,76,77
	57	8000	47,53,54,55,56,57,58,100
	81	7000	47,53,54,55,56,57,58
	109	7000	47,53,54,55,56,57,58
	141	7000	47,53,54,55,56,57,58
	172	7000	47,53,54,55,56,57,58
	212	7000	47,53,54,55,56,57,58
	263	8000	47,53,54,55,56,57,58,62
	291	7001	47,53,54,55,56,57,58
	317	7001	47,53,54,55,56,57,58
	365	8001	47,52,53,54,55,56,57,58

750 ppmv ClO_2, 75% RH, 12 hours, Computers On

decon 117	Day	Score	Failed Tests
	-95	0	
	1	5000	58,75,76,77,100
	29	0	
	57	0	
	85	Computer fails to boot - hard drive failure	

BioQuell 45g H_2O_2 injection, Computer Off

decon 104	Day	Score	Failed Tests
	-1	0	
	1	0	
	70	1	
	97	0	
	125	0	
	156	5000	59,60,61,62,63
	188	5000	59,60,61,62,63
	218	5000	59,60,61,62,63
	245	5000	59,60,61,62,63
	325	3000	59,61,62
	363	4000	59,60,61,62

BioQuell 45g H_2O_2 injection, Computer Off

decon 105	Day	Score	Failed Tests
	-1	0	
	1	1	
	69	0	
	106	0	
	126	0	
	159	0	
	195	0	
	232	0	
	272	0	
	317	0	
	366	0	

BioQuell 45g H_2O_2 injection, Computer On

decon 100

Day	Score	Failed Tests
1	0	
74	0	
102	0	
161	0	
195	0	
224	1	
252	0	
286	0	
330	3000	48,49,50
368	0	

BioQuell 45g H_2O_2 injection, Computer On

decon 101

Day	Score	Failed Tests
-8	0	
1	0	
69	11000	47,48,49,50,51,53,54,55,56,57,58
97	1000	76
125	3	
156	0	
190	3002	55,56,57
219	7000	52,53,54,55,56,57,58
247	13000	46,47,48,49,50,51,52,53,54,55,56,57,58
281	7000	47,53,54,55,56,57,58
325	3000	48,49,50
363	7000	47,53,54,55,56,57,58

BioQuell 45g H_2O_2 injection, Computer On

decon 102

Day	Score	Failed Tests
-8	0	
1	0	
68	15000	47,48,49,50,51,52,53,54,55,56,57,58,70,71,72
96	0	
124	0	
155	0	
189	4	
218	0	
246	2	
280	3000	48,49,92
324	8001	47,53,54,55,56,57,58,92
362	4000	48,49,50,92

Steris 250 ppmv H_2O_2, 4 hours, Computer Off

decon 112

Day	Score	Failed Tests
-54	0	
1	0	
28	0	
93	0	
179	0	
213	1000	62
248	1000	62
294	0	
332	0	
354	0	
371	0	

Steris 250 ppmv H_2O_2, 4 hours, Computer Off

decon 113

Day	Score	Failed Tests
-55	0	
1	0	
27	0	
56	1	
92	0	
122	0	
177	0	
212	0	
293	0	
324	3000	48,49,50
353	3000	48,49,50
370	2000	48,49

Steris 250 ppmv H_2O_2, 4 hours, Computers On

decon 109	Day	Score	Failed Tests
	-59	0	
	1	0	
	28	1	
	56	0	
	92	0	
	122	0	
	154	0	
	178	0	
	210	0	
	242	2000	48,49
	298	1000	48
	331	4001	47,48,49,50
	359	3001	48,49,50

Steris 250 ppmv H_2O_2, 4 hours, Computers On

decon 110	Day	Score	Failed Tests
	-56	0	
	1	0	
	27	12000	47,48,49,50,51,52,53,54,55,56,57,58
	55	3	
	91	2	
	121	4000	54,55,56,57
	153	4000	54,55,56,57
	177	5000	54,55,56,57,58
	209	5000	54,55,56,57,58
	241	4000	53,54,55,56
	297	5000	54,55,56,57,58
	330	5000	54,55,56,57,58
	358	4001	54,55,56,57

Steris 250 ppmv H_2O_2, 4 hours, Computer On

decon 111	Day	Score	Failed Tests
	-58	0	
	1	0	
	25	1	
	53	1	
	89	1	
	119	3000	54,55,56
	151	5000	54,55,56,57,58
	175	6000	47,54,55,56,57,58
	239	6000	47,54,55,56,57,58
	295	7000	47,54,55,56,57,58,62
	329	7000	47,53,54,55,56,57,58
	351	7000	47,53,54,55,56,57,58
	369	7002	47,53,54,55,56,57,58

The test numbers are described in Table 5-2. All yellow-highlighted test numbers are related to DVD drive components. Table 5-3 provides a total of all incidents of PC-Doctor® Service Center™ 6 tests that received a "Fail." For each test condition, the results are shown for each of the computers that underwent year-long testing.

The four computers missing from the list in Table 5-3 that were listed in Table 3-5 are the ones that were sent to Alcatel-Lucent for the detailed IA&E testing. These computers were Decon 108 (Control), Decon119 (3000 ppmv ClO_2), Decon 103 (BioQuell HPV, OFF), and Decon 114 (STERIS VHP, OFF).

Table 5-2. PC-Doctor® Failed Test Correlation to PC Subsystem Components

Failed PC-Doctor® Test	Subsystems	Test Description
1	SYSTEMS DETECTION	Does Computer correctly detect its systems?
13	Intel(R) Core™2 CPU 6400 @ 2.13GHz CPU:0	Multicore Test
23	Intel(R) Core™2 CPU 6400 @ 2.13GHz CPU:1	Multicore Test
26	512 MB DDR2-SDRAM (666 MHz)	Pattern Test
36		Modulo20 Test
37		Moving Inversion Test
46	HL-DT-ST DVD+-RW GSA-H31N	(DVD-RW Drive) Read Write Test
47		(CD-R Drive) Read Write Test
48		(DVD Drive) Linear Seek Test
49		(DVD Drive) Random Seek Test
50		(DVD Drive) Funnel Seek Test
51		(DVD Drive) Linear Read Compare Test
52		(DVD+R Drive) Read Write Test
53		(CD-RW Drive) Read Write Test
54		(CD-ROM Drive) Linear Seek Test
55		(CD-ROM Drive) Random Seek Test
56		(CD-ROM Drive) Funnel Seek Test
57		(CD-ROM Drive) Linear Read Compare Test
58		(CD-ROM Drive) CD Audio Test
59	Floppy disk drive	Linear Seek Test
60		Random Seek Test
61		Funnel Seek Test
62		Surface Scan Test
63		Pattern Test
70	Broadcom NetXtreme 57xx Gigabit Controller	Network Link Test
71		TCP/IP Internal Loopback Test
72		Network External Loopback Test
75	SoundMAX Integrated Digital HD Audio Driver	Sound Interactive Test
76		
77	Intel(R) Q965/Q963 Express Chipset Family	AVI Interactive Test
92	PCDoctor® USB Test Key 2.0 USB Device	Scan Test Port 6
100	SoundMAX Integrated Digital HD Audio Driver	Rough Audio Test

Table 5-3. Total "Fail" Results over Year-Long Observation and Testing Period

Fumigation Technology	None	3000 ppmv ClO_2, 3 hr.	3000 ppmv ClO_2, 3 hr.	750 ppmv ClO_2, 12 hr.	BioQuell, 45 g H_2O_2 injection, 1 hr dwell	BioQuell, 45 g H_2O_2 injection, 1 hr dwell	Steris, 250 ppmv H_2O_2, 4 hr dwell	Steris, 250 ppmv H_2O_2, 4 hr dwell
Test Condition	**Computer Off**	**Computer Off**	**Computer On**	**Computer On**	**Computer Off**	**Computer On**	**Computer Off**	**Computer On**
Computer A	74	0	0	50[HD]	27	3	2	10
Computer B	0	15	0	93	0	52	8	48
Computer C	NA	NA	5	5 [HD]	NA	30	NA	48

NA = Not Applicable. These computers were sent to Alcatel-Lucent for detailed IA&E testing.
HD = Hard drive failure.

As an example, Table 5-1 shows DECON106 with a score of 5,000 for Day 103 (after fumigation) and 12001 for Day 302. These numbers mean that during Day 103 testing, 5 specific tests received a "Fail" or "False-Fail" during testing (5 x 1,000), while during Day 302, 1 test received a "Pass2" (1 x 1) and 12 tests received a "Fail" or "False-Fail" (12 x 1,000). The column to the right shows the ID of the test(s) that failed. By cross-referencing these *Failed Test* numbers (54 through 58) with Table 5-2, one can determine that on Day 103, all failures were related to the CD drive. Because the DVD/CD drive is a frequent cause of failure, these have been highlighted in yellow. During Day 225 testing, two tests IDs (60 and 61) received a "Fail" but were not highlighted; Table 5-2 identifies these tests as testing the floppy disk drive.

As the failed tests in Table 5-1 were examined, regardless of fumigation scenario, the vast majority (83.3%) were found to be related to the DVD drive (yellow highlight). No information was available to ascertain which drive component failed. A significant amount of the remaining failures (14%) were related to the floppy drive. Other failures, each one accounting for no more than 3.7 percent of the total failures during the year-long testing period, included a broken USB port (physically broken, perhaps due to repeated use), "False-Fail" detections of processor and memory capability, and intermittent sound card and network controller failures. The intermittent "Pass 2" results (each shown in Table 5-1 as a score of 1) also point to vulnerabilities in the same subsystems (DVD and floppy drives).

In most cases, comparison of the results from fumigated computers to the control computer set does not suggest that fumigation significantly affected the performance of the computer. The CD/DVD drive in one control computer performed very poorly, seemingly related to a SCSI interface. Many of the CD/DVD failures in other computers also indicated a failure in the SCSI interface.

However, profound effects of 750 ppmv ClO_2 fumigation were seen when two of the three computers lost all functionality. Decon 115 experienced intermittent "Blue Screens of Death" and PC-Doctor® Tests Batch 4 failures before losing the ability to run the Windows® operating system on day 212 after fumigation. On day 82 after fumigation, Decon 117 was unable to run Windows®. Decon 117 ran in DOS, until it experienced a complete failure to power on day 109 after fumigation.

When Decon 115 failed to power on, the monitor was switched with the one from Decon 117. The possibility of system damage to Decon 117 resulting from the use of faulty equipment from Decon 115 is unlikely but cannot be discounted. Even though PC-Doctor® was run monthly, PC-Doctor® gave no indication of upcoming computer failures. For example, DECON 117 ran flawlessly for two months prior to its system failure.

Corrosion or corrosion by-products following ClO_2 fumigation probably caused failures in one of the subsystems involved in writing to disk, such as Random Access Memory (RAM), the cache, or the disk controller. We have seen notable failures in the dual in-line memory module (DIMM) RAM in previous research. The failure, wherever it was, prevented proper writing of the registry, probably on shutdown. This error caused unrecoverable failure of the machine.

The harsh nature of the 750 ppmv ClO_2 fumigation conditions was noted when severe corrosion was seen on the CPU heat sink fins and rust was observed on the power supply interior and exterior screens on all three computers on the day following fumigation. All three computers experienced high levels of physical and functional deterioration over the 12 month observation period. The 750 ppmv ClO_2 fumigation condition proved to be unsuitable for the Category 4 materials.

Not listed here are other intermittent problems associated with a computer but not detected during PC-Doctor® Service Center™ 6 testing. In particular, Decon 118 (3000 ppmv ClO_2), which had zero PC-Doctor® Service Center™ 6 failures, suffered 3 "Blue Screens of Death" over the year-long study. This observation suggests that significant damage may have occurred due to fumigation that was not detected by PC-Doctor® Service Center™ 6.

6.0 Fumigation Effectiveness and Fumigation Safety

6.1 Fumigation Effectiveness

BIs were used to obtain an indication of the potential impact of local conditions on the effectiveness of the fumigation process to inactivate spores potentially located within the computer. Specifically, the *B. atrophaeus* BIs were used to investigate ClO_2 sporicidal effectiveness and *Geobacillus stearothermophilus* BIs were used to investigate H_2O_2 sporicidal effectiveness, both in the bulk chamber and for localized hot spots inside the computers where the RH may be lower because of the heat generated by the computer electronics during operation. The BIs provided a qualitative result of growth or no growth after an incubation period of seven days. BIs have been shown not to correlate directly with achieving target fumigation conditions for BA spores or inactivation of spores on common building surfaces.[7] While BIs do not necessary indicate achievement, they provide a sufficient indication of a failure to achieve successful fumigation conditions.[7]

Figures 6-1 and 6-2 show the locations of the BIs within each computer. These locations were chosen based on the available mounting surfaces that afforded relatively unrestricted air flow. Two BIs were placed on the side cover (Figure 6-1) in areas of high air flow. Three more BIs (Figure 6-2) were placed inside the computer to capture both high and low air flow locations. BIs were also present in the MEC chamber, one on top of each Category 4 computer case and two between the keyboards and monitors on the top shelf of the MEC chamber.

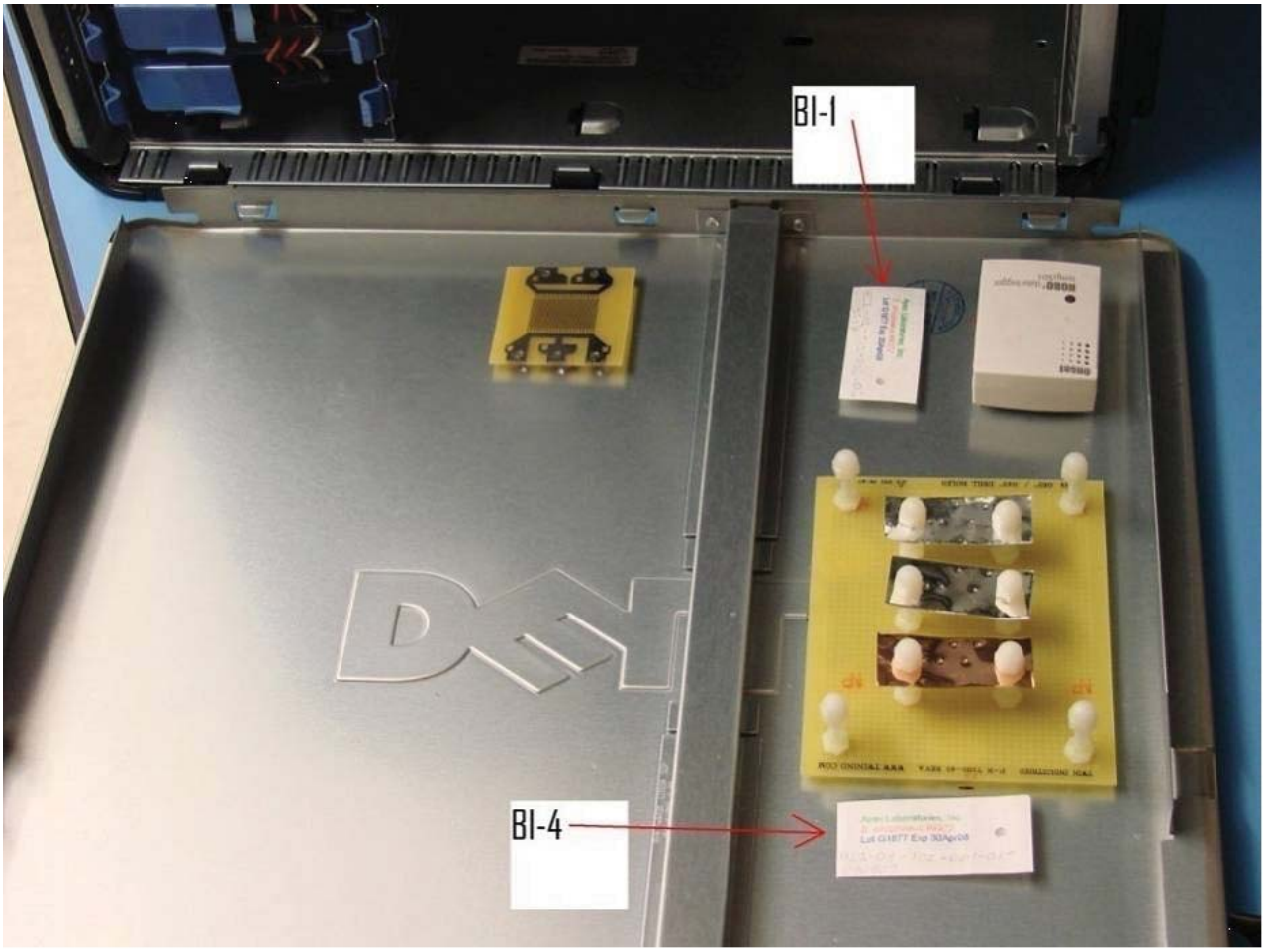


Figure 6-1. Location of two of the five BIs inside the computer side cover.

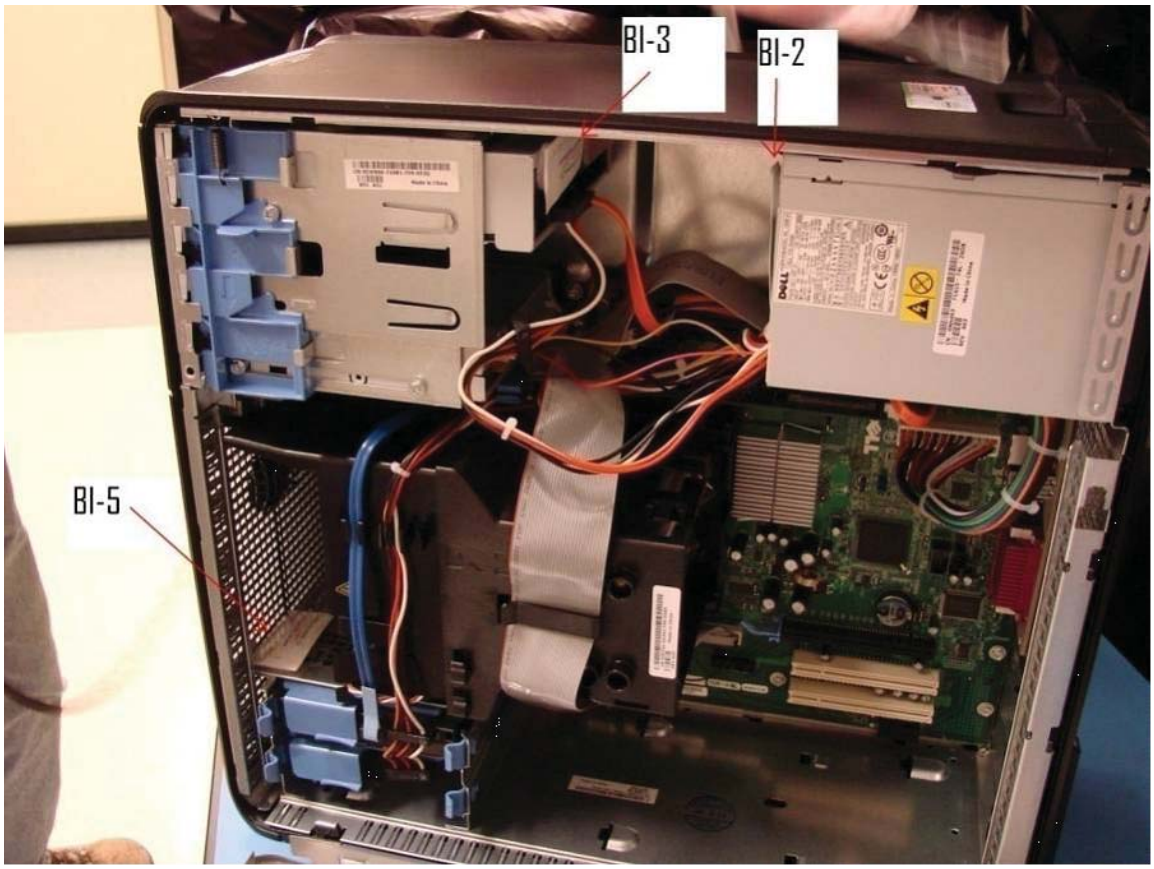


Figure 6-2. Location of the remaining three BIs in both high and low air flow locations inside the computer.

Table 6-1 details the effect of each fumigation scenario on BI viability in both the fumigation chamber and inside the computers. BIs were not placed in the control runs that were conducted without fumigant since control BIs accompanied each set of fumigated BIs. Note that different BIs were used with the two different fumigants, and that for H_2O_2 fumigations, three separate fumigations were used to test conditions simultaneously, so the chamber BIs are grouped across test conditions.

Table 6-1. BI Deactivation in the Chamber and Computers for each Fumigation Scenario

Fumigation Technology	None	BioQuell, 45 g H_2O_2 injection, 1 hr dwell		BioQuell, 45 g H_2O_2 injection, 1 hr dwell		3000 ppmv ClO_2, 3 hr.	3000 ppmv ClO_2, 3 hr.	750 ppmv ClO_2, 12 hr.
Test Condition	Computer Off	Computer Off	Computer On	Computer Off	Computer On	Computer On, Idle	Computer On, Active	Computer On, Idle
Chamber		100		93		N/A	100	N/A
Computer A		100	100	80	100	N/A	100	N/A
Computer B		100	100	80	20	N/A	100	N/A
Computer C		100	100	100	100	N/A	80	N/A

N/A – Data not available

All BIs used during the BioQuell fumigations were deactivated, in contrast to the efficacy of the STERIS fumigation conditions. The second fumigation ("Computer B") seemed particularly ineffective, though the test conditions (as shown in Table 6-2) were in the same range as the first and third fumigation. Fumigation B accounted for the only chamber BI that was not deactivated.

Fumigation B showed a significant difference in the deactivation of STERIS BIs in the OFF computer versus the ON computer. One explanation for this observation might be that the higher temperature experienced in the ON computer decreased the RH and decreased the efficacy of the fumigant.

BI placement did not seem to be a factor in deactivation. In STERIS Fumigation A, BI5, the location with the highest air flow, was the only BI that was not deactivated. For Fumigation B, BI4 was the only BI deactivated in the OFF computers, and the only BI not deactivated in the ON computers. Variation in the BIs themselves may be more responsible for these results than the small local variations in the RH and temperature within a single computer.

6.2 Health and Safety Effects after Fumigation

As discussed in Section 4.3 and in previous reports,[5] fumigation with ClO_2 produced large amounts of dust inside the computers. When the computers were opened the dust could be seen and an acrid smell (attributed to hydrogen chloride) could be sensed. Vacuuming of the visible dust not only served to remove the majority of this probable health hazard and prevent the dust from being spread outside the computers by the cooling fan or during maintenance and cleaning procedures, but also may have assisted in keeping all computers almost fully operational after an entire calendar year.

No dust was produced following fumigation with H_2O_2, nor were any other by-products of fumigation detected.

Table 6-2. Average Conditions during STERIS Fumigation

Fumigation	H_2O_2 (ppmv)	Temperature (°C)	RH (%)	Dwell CT (ppmv*hours)	Dwell length (minutes)
A	245.6	28.7	33.4	1049.4	252.4
B	252.2	30.2	31.0	1067.9	263.3
C	235.5	29.2	32.2	1100.2	274.7

7.0
Quality Assurance

The objective of this study was to assess the impact of H_2O_2 on material and electronic equipment due to fumigation at conditions known to be effective against biological threats. The Data Quality Objectives (DQOs) address this impact using visual inspection (both externally and internally) to assess the loss in value or use of the tested material/equipment, as well as functionality of the material/electronic equipment. The following measurements were considered critical to accomplishing part or all of the project objectives:

- Real-time fumigant concentrations
- Temperature
- RH
- Fumigation time sequence
- Material inspection and electronic equipment functionality time sequence
- Growth/no growth of the BIs.

7.1 Data Quality

The QAPP[22] in place for this testing was followed with few deviations; many of the deviations were documented in the text above. Deviations included needing a stand-alone control system for the STERIS and reducing frequency of visual inspections. These deviations did not substantially affect data quality. The HOBO® data did not result in a reliable data set.

7.1.1 Data Quality Indicator Goals for Critical Measurements

The Data Quality Indicators (DQIs) listed in Table 7-1 are specific criteria used to quantify how well the collected data meet the Data Quality Objectives (DQOs).

Table 7-1. DQIs for Critical Measurements

Measurement Parameter	Analysis Method	Accuracy	Detection Limit	Completeness[1] %
Real-time ClO_2 concentration at the exit of the MEC test Chamber	ClorDiSys EMS monitor (0.1 – 30 mg/L)	15% of SM-4500-E	0.1 mg/L 36 ppm	95
Real-time ClO_2 concentration inside the MEC test Chamber	ClorDiSys GMP monitor (0.1 – 30 mg/L)	15% of SM-4500-E	0.1 mg/L 36 ppm	95
Extracted ClO_2, high concentration	Modified SM 4500-ClO_2 E	5% of Standard	0.1 mg/L (solution)	100
Real-time H_2O_2 concentration inside the MEC test Chamber	Analytical Technology Corp. electrochemical sensor	± 10% full scale from factory	1 ppm	95
Extracted H_2O_2 concentration inside the MEC test Chamber	OSHA VI-6 Method	3% of prepared standard solution	0.1 ppm for 100 L sample	100
Relative humidity	RH probes (0-100 %)	± 5.0 % full scale[2] from factory	NA	95
Differential time	Computer clock	1 % of reading	0.5 sec	95
Temperature inside the isolation chamber	Thermocouple	± 2 °F	NA	95

[1]Completeness goals of 100 % are used for those parameters that are performed manually and infrequently; 95 % is used for those data streams that will be logged automatically.
[2] Stated as 3.5% in QAPP however, at the time we were using the criteria of ± 5% to determine if we should switch sensors.

The accuracy goal for the ClorDiSys EMS monitor was modified to 15% of the SM-4500E from ± 0.3 mg/L of the GMP. This change was necessary because the SM-4500-E samples were the basis on which the concentration inside the MEC test chamber was determined, not the GMP monitor. Also, the accuracy of the GMP monitor is determined by the SM-4500-E titration. The same should therefore be the case for the EMS monitor.

The accuracy goal for the Analytical Technology Corp. electrochemical sensor, or ATI, was modified from factory from 5% of reading (stated in the QAPP) to ± 10% full scale to reflect the actual factory specification for this instrument

The QAPP originally stated that the target accuracy for the RH probes would be 3.5% full scale from factory. However; the factory specification is 5% full scale from factory. The accuracy goal for the RH probe was subsequently modified to reflect the factory specification.

7.1.2 Data Quality Indicators Results

The accuracy of the real-time ClO_2 monitors was assessed with respect to the Modified SM 4500-ClO_2 E Method. Iodometric titration was the intended method for assessing the accuracy of the real time or H_2O_2 monitor, but this method proved to be unreliable. Corrections to the real time concentration set-point were made so that the target concentration was attained according to the titration measurement. Accuracy of the real-time ClO_2 and H_2O_2 monitors was not evaluated due to unavailability of a constant-concentration source and the feedback nature of their operation in this specific testing setup. The accuracy of the extractive titration was assessed with respect to a standard solution.

7.1.2.1 H_2O_2 Fumigations

Tables 7-2 and 7-3 show the actual DQIs for the H_2O_2 fumigations using BioQuell and STERIS.

Table 7-2. DQIs for Critical Measurements for BioQuell Fumigations

Measurement Parameter	Fumigation A		Fumigation B		Fumigation C	
	Accuracy (%)	Completeness (%)	Accuracy (%)	Completeness (%)	Accuracy (%)	Completeness (%)
Real-time H_2O_2 concentration inside the MEC test Chamber	±10%[1]	100	±10%[1]	100	±10%[1]	100
Extracted H_2O_2 concentration inside the MEC test Chamber	NA[2]	NA[2]	NA[2]	NA[2]	NA[2]	NA[2]
RH probes (0-100 %)	15	NA	1	100	0	67%
Differential Time	1.0	100	1.0	100	1.0	100
Thermocouple	0	100	1	100	0	1

[1]The ATIs were zeroed and spanned with a standard H2O2(V) prior to each test and were within the factory specifications during each BioQuell fumigation.
[2]The accuracy for the extracted H2O2 concentration inside the MEC test chamber could not be determined due to the unavailability of a H2O2(V) standard for the OSHA VI-6 Method as a basis for comparison.

During BioQuell Fumigation A, the RH probe did not meet the accuracy goal of ± 5%. RH probe data for Fumigations B and C satisfied all accuracy and completeness requirements.

The 60 minute BioQuell fumigations required that data be logged every 10 seconds in order to meet the accuracy requirement for differential time. The actual logging interval was 10 seconds, so all fumigations met the requirement.

The thermocouple met the accuracy and completeness requirements for all BioQuell fumigations.

Table 7-3. DQIs for Critical Measurements for Steris Fumigations

Measurement Parameter	Fumigation A		Fumigation B		Fumigation C	
	Accuracy (%)	Completeness (%)	Accuracy (%)	Completeness (%)	Accuracy (%)	Completeness (%)
Real-time H_2O_2 concentration inside the MEC test Chamber	±10%[1]	100	+/-10%[1]	100	±10%[1]	100
Extracted H_2O_2 concentration inside the MEC test Chamber	NA[2]	NA[2]	NA[2]	NA[2]	NA[2]	NA[2]
RH probes (0-100 %)	3.6	100	6.6	NA	1.3	67 %
Differential Time	0.25	100	0.25	100	0.63	100
Thermocouple	2	100	1	100	1	100

[1]The ATIs were zeroed and spanned with a standard H2O2(V) prior to each test and were within the factory specifications during each BioQuell fumigation.
[2]The accuracy for the extracted H2O2 concentration inside the MEC test chamber could not be determined due to the unavailability of a H2O2(V) standard for the OSHA VI-6 Method as a basis for comparison.

The RH probe met the accuracy goals for all STERIS fumigations except Fumigation B. For this test, the probe slightly exceeded the target of ± 5%.

Differential time and thermocouple requirements were satisfied for all STERIS fumigations.

7.1.2.2 ClO_2 Fumigations

Table 7-4 shows how the DQI parameters met the goals for the ClO_2 fumigation during exposure.

Table 7-4. DQIs for Critical Measurements for ClO_2 Fumigations

Measurement Parameter	Fumigation A		Fumigation B	
	Accuracy (%)	Completeness (%)	Accuracy (%)	Completeness (%)
ClorDiSys EMS monitor (0.1 – 30 mg/L)	39	0	8.5	**84.6**
ClorDiSys GMP monitor (0.1 – 30 mg/L)	18	16.6	11.2	90.9
Modified SM 4500-ClO_2 E	2	100	2	100
RH probes (0-100 %)	2.9	100.0	NA	NA
Differential Time	0.08	100	0.33	100
Thermocouple	± 1.5°F	100	± 2.0°F	99.7

Neither the accuracy nor the completeness criteria for the EMS monitor were met for ClO_2 Fumigation A. The EMS monitor consistently read lower than the SM-4500-E throughout the duration of the test. Fumigation B met the accuracy goals for the EMS monitor.

Both STERIS fumigations met the accuracy and completeness goals for all other parameters with the exception of the RH probe for Fumigation B. The same probe was used for Fumigation B; unfortunately, there was no relative humidity comparison performed between a standard and the probe to determine the probe's accuracy.

7.2 Quantitative Acceptance Criteria

The quantitative acceptance criteria were associated with targeted setting conditions in the MEC test chambers during the entire exposure time. These acceptance criteria are listed in Table 7-5.

Table 7-5. Acceptance Criteria for Critical Measurements

Measurement Parameter	Analysis Method	Precision RSD (%)
Real-time ClO_2 concentration inside the MEC test chamber	ClorDiSys GMP monitor (0.1 – 30 mg/L), Interscan LD223 (0-200 ppm-with dilution)	± 10%
Extracted ClO_2 inside the MEC test chamber	Modified SM 4500-ClO_2 E	± 15%
Real-time H_2O_2 concentration inside the MEC test chamber	Analytical Technology Corp. electrochemical sensor	± 5%
Extracted H_2O_2 inside the MEC test chamber	OSHA VI-6 Method	± 10%
Relative humidity inside both the MEC test and control chambers	RH probes (0-100 %)	± 5%
Temperature inside both the MEC test and control chambers	Thermistor	± 5%

7.2.1 Quantitative Acceptance Criteria Results

7.2.1.1 H_2O_2 Fumigations

Table 7-6 shows the precision expressed in RSD (%) for the BioQuell fumigations during injection.

Table 7-6. Precision (RSD %) Criteria for BioQuell Fumigations

Measurement Parameter	Fumigation		
	A	B	C
Analytical Technology Corp. electrochemical sensor	NA	NA	NA
OSHA VI-6 Method	NA[3]	NA[3]	NA[3]
RH probes (0-100 %)	3.5	3.1	4.0
Thermistor	1.2	0.6	1.1

[3] The accuracy for the extracted H^2O_2 concentration inside the MEC test chamber could not be determined due to the unavailability of a H_2O_2(V) standard for the OSHA VI-6 Method as a basis for comparison.

The precision of the BioQuell data could not be determined due to the nature of the fumigations. Proper operation of the BioQuell system is not dependent on concentration, but on achieving condensation conditions by varying starting RH, injection amounts, and dwell time.

The OSHA VI-6 Method for extractive sampling proved to be unreliable therefore the results from this method were excluded from use during data analysis.

Table 7-7 shows the precision expressed in RSD (%) for the STERIS fumigations during dwell time.

Table 7-7. Precision (RSD %) Criteria for STERIS Fumigations

Measurement Parameter	Fumigation		
	A	B	C
Analytical Technology Corp. electrochemical sensor	NA	NA	NA
OSHA VI-6 Method	NA[3]	NA[3]	NA[3]
RH probes (0-100 %)	2.7	2.2	1.5
Thermistor	1.1	2.3	0.9

[3] The accuracy for the extracted H_2O_2 concentration inside the MEC test chamber could not be determined due to the unavailability of a H_2O_2(V) standard for the OSHA VI-6 Method as a basis for comparison.

7.2.1.2 ClO_2 Fumigations

Table 7-8 shows the precision expressed in RSD (%) for the ClO2

Table 7-8. Precision (RSD %) Criteria for ClO_2 Fumigations

Measurement Parameter	Fumigation	
	A	B
ClorDiSys GMP monitor (0.1 – 30 mg/L), Interscan LD223 (0-200 ppm-with dilution)	4.7	4.7
Modified SM 4500-ClO2 E	4.5	0.0
RH probes (0-100 %)	0.1	1.3
Thermistor	0.7	0.5

All data from ClO_2 fumigation satisfied the precision requirements.

7.3 Audits

This project was assigned Quality Assurance (QA) Category III and did not require technical systems or performance evaluation audits.

8.0
Conclusion

All Category 2 and 3 materials demonstrated sufficient compatibility with H_2O_2 vapor. The only reported functionality failure was with a PDA and it is inconclusive whether the failure was a result of H_2O_2 vapor exposure or a random equipment failure.

In this study, all Category 2 and 3 materials proved to be resistant to H_2O_2 exposure under all conditions tested. As discussed in previous reports,[5] ClO_2 gas can cause severe corrosion on several types of structural materials and discoloration of wiring insulation. Exposure to H_2O_2 vapor resulted in none of the damaging effects of the ClO_2 gas. Hydrogen peroxide (H_2O_2), therefore, can be considered the more compatible fumigant of the two.

Alcatel-Lucent reported noticeable damage to optical plastics following H_2O_2 fumigations.[15] The limited sample size for these long term tests did not allow confirmation of those results, as one of the two control computers suffered more DVD failures than any fumigated one.

Results from the 750 ppmv ClO_2 fumigation suggest that 750 ppmv was more damaging to Category 4 materials than the 3000 ppmv ClO_2 fumigation. Although both fumigation concentrations resulted in severe physical damage to the computers by promoting rusting and corrosion, only the computers exposed to 750 ppmv ClO_2 experienced unrecoverable failures. It is not readily understood why the lower concentration (same RH) fumigation was more damaging; however, the same sample size and difference in computer batches cannot be ruled out as confounding parameters.

9.0 Recommendations

This section provides recommendations resulting from the experiments. The recommendations relate to functional failures of various tested materials and electronic components that were subjected to decontamination scenarios using ClO_2. There were no documented effects or failures associated with the use of vaporized H_2O_2, with the exception of noticeable damage found by Alcatel-Lucent on optical plastics following H_2O_2 fumigations. Recommendations for the use of both fumigants are presented below.

9.1 Corrective Actions

Corrective actions can be implemented immediately after the fumigation event to reduce/prevent further degradation of sensitive materials and components. These corrective actions include making copies of all sensitive documents and electronic records as if they were going to be altered, and replacing optical devices in critical components.

9.2 Listing of "At Risk" Material and Electronic Components

During the planning stages of a remediation, inventory at-risk components, including those that contain affected subsystems, such as optical disc drives. These components could be candidates for alternative decontamination techniques or immediate replacement after fumigation.

9.3 Further Research

A research plan to investigate additional materials/ electronic component compatibilities that are vital to other high-end electronic equipment, but not covered under these experiments, can be developed to assist with the recommendation in Section 9.2. The list may include the compatibility of lubricated metals, aluminum alloys, and other types of plastic used in the electronics industry. As more information becomes available on the effectiveness of additional fumigation conditions, investigation of these additional fumigation conditions is important. In planning activities for remediation, the inventory of at-risk items and components can be done so that these items and components can be identified for special alternative decontamination procedures or immediate replacement.

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Appendix A:
Computers Specifications for Category 4 Testing

Base Unit	Dell™ OptiPlex™ 745 Minitower, Intel® Core™ 2 Duo E6400/2.13GHz, 2M, 1066FSB (222-5690)
Processor	NTFS File System, Factory Install (420-3699)
Memory	512MB, Non-ECC, 667MHz DDR2 1x512, Dell™ OptiPlex™ 745 (311-5037)
Keyboard	Dell™ USB Keyboard, No Hot Keys, English, Black, OptiPlex™ (310-8010)
Monitor	Dell™ E157FP,15 Inch Flat Panel 15.0 Inch Viewable Image Size, OptiPlex™ and Latitude™ (320-4962)
Video Card	Integrated Video, Intel® GMA3000, Dell™ OptiPlex™ 745 (320-5169)
Hard Drive	80GB SATA 3.0Gb/s and 8MB Data Burst Cache™, Dell™ OptiPlex™ 320 and 745 (341-4214)
Floppy Disk Drive	3.5 inch,1.44MB,Floppy Drive Dell™ OptiPlex™ 320 and 745 Desktop or Minitower (341-3840)
Operating System	Microsoft Windows® XP Professional Service Pack 2, with Media, Dell™ OptiPlex™ 320, 740 and 745 English, Factory Install (420-6287)
Mouse	Dell™ USB 2-Button Entry Mouse with Scroll, Black, OptiPlex™ (310-8008)
TBU	RoHS Compliant Lead Free Chassis and Motherboard, Dell™ OptiPlex™ (464-1131)
CD-ROM or DVD-ROM Drive	16X DVD±RW SATA, Black, Roxio Creator™ Dell™ Edition, Dell™ OptiPlex™ 745 Desktop or Minitower (313-4378)
Speakers	No Speaker, Dell™ OptiPlex™ (313-1416)
Documentation Diskette	Resource CD contains Diagnostics and Drivers for Dell™ OptiPlex™ Systems (313-7168)
Factory Installed Software	Energy Smart, Energy Star Labeling, EIST for Dell™ OptiPlex™ (if applicable) (310-8344)
Service	Non-Standard Service Option (900-9006)
Service	Type 6 Contract -Next Business Day Parts Delivery, Initial Year (980-4740)
Service	Dell™ Hardware Warranty, Initial Year (985-2477)
Service	Dell™ Hardware Warranty, Extended Year(s) (985-2478)
Service	Type 6 Contract -Next Business Day Parts Delivery, 2 yr Extended (970-8672)
Installation	Standard On-Site Installation Declined (900-9987)
Service One	Dell™ Federal KYHD Service (980-3067)

Appendix B:
Parts List of Copper Aluminum Service Panels

C.E.S. (Garner)
214-A Garner Business Court,
Garner NC, 27529.

Phone: 919-661-1155
Fax: 919-661-8866
Email: Garner0015@ces-us.net

PACKING SLIP

GAR/031103

Date: 01 Oct 2008

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Entered by: Robert Carr

Account: 00150396001

Order Number: EPA

ARCADIS US INC
4915 PROSPECTUS DR
SUITE F
DURHAM NC
27713

Qty	Item	Description	$ Price Per	$ Goods
84	BR110	SP 10A BR BREAKER	5.27 E	442.68 *
1	SHIPPING & HANDLING	SHIPPING & HANDLING	82.15 E	82.15 *
14	P&S PS5266-X	15A 125V PLUG	6.86 E	96.04
100	SO-14/3	SO-14/3	936.02 M	93.60
14	MADISON MCG-50A560	1/2 CORD CONN	449.00 C	62.86
14	C-H BR24L70FGP	70A MLO FL LD CTR	26.00 E	364.00
100	MADISON L-51	3/8 2SCR NMC CONN	25.30 C	25.30
30	NM-B-14/2 ALUM	14/2 ALUM ROMEX	500.00 M	15.00
250	NM-B-14/2-CU-250C	NM-B-14/2-CU-WG-250CL	215.00 M	53.75
14	RACO 192	4SQ 1-1/2D BOX COMB KO	94.50 C	13.23
7	P&S 3232-I	DPLX RCPT-NEMA5-15R	55.00 C	3.85
7	P&S 660-IG	SP 15A120V GRD AC SW	74.50 C	5.22
14	MADISON CPB-50	1/2 PLSTC INS BUSH	12.86 C	1.80
14	P&S TPJ18-I	IV 2G TOG/DPLX PLT	66.07 C	9.25
14	RACO 778	4-IN SQ 1/2D 2G SW RING	183.74 C	25.72

Goods Total: $1294.45
Tax Total: $87.38
Total: $1381.83

Signature: _____ Print Name: _____

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GOODS ARE SOLD ACCORDING TO VENDORS AND OUR OWN CONDITIONS OF SALE, COPIES OF WHICH ARE AVAILABLE UPON REQUEST.

E&OE DM/01

Appendix C:
Subsystems of Category 4 Computers (Provided by Alcatel-Lucent)

#	Major subsystem	Description	Chipsets involved	PC-Doctor® Tests this subsystem (yes/no)
1	Motherboard	Dual processor CPU chip	Intel® Core™ 2 Duo E6400	y
2	Motherboard	Dual processor CPU heat sink	Intel® Core™ 2 Duo E6400	y
3	Motherboard	IO Controller IC	Intel® 82801HB/82801HR ICH8	y
4	Motherboard	CMOS (CMOS RAM with RTC & NVRAM)	Intel® 82801HB/82801HR ICH8	y
5	Motherboard	SDRAM memory cards (DIMM)	Hyundai 512 MB DDRW-SDRAM	y
6	Motherboard card connector	SRAM DIMM module board mounted connector		y
7	Motherboard	Graphics and Memory Controller Hub	Intel® 82Q965	y
8	Motherboard	Intel 82Q965 heat sink	Intel® 82Q966	y
9	Motherboard	SPI (Serial Peripheral Interface) Flash Device: ROM BIOS FWH (firmware hub) : contains BIOS Setup program POST, PCI auto-config and Plug&Play support	MXIC MX25L8005	y
10	Motherboard	SuperIO Controller (contains floppy drive controller, serial port controller, parallel port controller, power management (fan) controller	SMSC SCH5514D-NS	y
11	Motherboard	LPC Interface TPM (Trusted Platform Module) protects signature keys and encryption		n
12	Motherboard	LAN-On-Motherboard (NIC) with 10/100/GbE support	Broadcom BCM5754KM Ethernet NIC and ATMEL AT45DB001B Flash SPI memory device	y
13	Motherboard	Battery (3V Lithium)	Panasonic CR2032 3V	y
14	Motherboard	Audio CODEC (compression/decompression)	Analog Devices HO Audio SoundMAX CODEC AD1983	y
15	Motherboard	Frequency timing generator/Real time clock	Intel® Core 2 Duo E6400, ICS9LP5052 and 32.768k crystal clock chip	y
16	Motherboard	battery -- mount and socket		n
17	Motherboard cable connector	SATA Drive0 (hard drive)	Intel® 82801HB/82801HR ICH8	y
18	Motherboard cable connector	SATA Drive1 (DVD drive)	Intel® 82801HB/82801HR ICH8	y
19	Motherboard cable connector	SATA Drive4 (not connected)	Intel® 82801HB/82801HR ICH8	n
20	Motherboard cable connector	SATA Drive5 (not connected)	Intel®82801HB/82801HR ICH8	n
21	Motherboard cable connector	Front Panel Connector (ON/OFF switch, 2 USB ports, front audio in/out ports)		y
22	Motherboard card connector	PCI Expressx16 connector (SLOT1) (not connected)		n
23	Motherboard card connector	PCI Expressx16 connector (SLOT4) (not connected)		n
24	Motherboard card connector	PCI Connector (SLOT2)		y

#	Major subsystem	Description	Chipsets involved	PC-Doctor® Tests this subsystem (yes/no)
25	Motherboard card connector	PCI Connector (SLOT3)		y
26	Motherboard cable connector	Floppy drive connector		y
27	Motherboard cable connector	Serial connector (not connected)		n
28	Motherboard cable connector	Fan connector		n
29	Motherboard cable connector	Internal Speaker connector (not connected)		n
30	Motherboard cable connector	Processor power connector (4 pin)		y
31	Motherboard cable connector	Main power connector (24 pin)		y
32	Motherboard component	Beep speaker		n
33	Motherboard component	Capacitor		n
34	Motherboard component	Resistor		n
35	Motherboard component	Transistor		n
36	Motherboard component	Choke		n
37	Motherboard component	Solder bond pad -- specify location		n
38	Motherboard component	screws and other mounting hardware		n
39	Fan	Main chassis fan		n
40	Power supply module	Electrical function		y
41	Power supply module	Mains power plugs (110V)		n
42	Power supply module	Chassis		n
43	Power supply cable to motherboard 24 pin connector	Power cable		y
44	Floppy disk drive	Chassis		n
45	Floppy disk drive	Motor		y
46	Floppy disk drive	Head		y
47	Floppy disk drive	Power connector		y
48	Floppy disk drive	Power cable		y
49	Floppy disk drive	Data cable		y
50	Hard drive	Chassis		n
51	Hard drive	Motor		y
52	Hard drive	Head		y
53	Hard drive	Power connector		y
54	Hard drive	Power cable		y
55	Hard drive	Data cable		y
56	DVD Drive	Chassis		n
57	DVD Drive	Drive motor		y
58	DVD Drive	Head		y
59	DVD Drive	Power connector		y
60	DVD Drive	Power cable		y
61	DVD Drive	Data cable		y
62	DVD Drive	Drawer open/close on chassis		y
63	Monitor	Screen		y
64	Monitor	Data Cable		y
65	Monitor	Data Cable connector		y
66	Monitor	Power Cable		y

#	Major subsystem	Description	Chipsets involved	PC-Doctor® Tests this subsystem (yes/no)
67	Monitor	Power Cable 110V plug		y
68	Monitor	Video connector on chassis		y
69	Monitor	Base of monitor stand		n
70	Mouse	USB Data Cable		y
71	Mouse	Mechanical operation		y
72	Keyboard	USB Data Cable		y
73	Keyboard	Mechanical operation		y
74	Communications Port COM1	COM1 connector on chassis		y
75	Printer Port LPT1	LPT1 connector on chassis		y
76	USB Port 1 keyboard	USB connector on chassis		y
77	USB Port 2 mouse	USB connector on chassis		y
78	USB Port 1	USB connector on chassis		y
79	USB Port 2	USB connector on chassis		y
80	USB Port 3	USB connector on chassis		y
81	USB Port 4	USB connector on chassis		y
82	USB Port 5	USB connector on chassis		y
83	USB Port 6	USB connector on chassis		y
84	Network (LAN) Port	Network (LAN) adapter connector on chassis		y
85	Audio out	Audio line out connector (green) on chassis		y
86	Audio in	Audio line in connector (blue & pink) on chassis		y
87	CASE	Removable side of case		n
88	CASE	Case interior floor		n
89	CASE	Case back panel screens		n
90	CASE	Case front panel		n
91	CASE	PCI Plates		n
92	CASE	Release Latch		n
93	CASE	Screws on exterior		n

Appendix D:
PC-Doctor® Service Center™ 6 Tests

Test #	Test
System Board	
1	RTC Rollover Test
2	RTC Accuracy Test
Intel® Core™ 2 CPU 6400 @ 2.13GHz CPU:0	
3	Register Test
4	Level 2 Cache Test
5	Math Register Test
6	MMX Test
7	SSE Test
8	SSE2 Test
9	SSE3 Test
10	SSSE3 Test
11	Stress Test
12	Multicore Test
Intel® Core™ 2 CPU 6400 @ 2.13GHz CPU:1	
13	Register Test
14	Level 2 Cache Test
15	Math Register Test
16	MMX Test
17	SSE Test
18	SSE2 Test
19	SSE3 Test
20	SSSE3 Test
21	Stress Test
22	Multicore Test
CMOS	
23	Checksum Test
24	Pattern Test
512 MB DDR2-SDRAM (666 MHz)	
25	Pattern Test
26	Advanced Pattern Test
27	Bit Low Test
28	Bit High Test
29	Nibble Move Test
30	Checkerboard Test
31	Walking One Left Test
32	Walking One Right Test
33	Auxiliary Pattern Test
34	Address Test
35	Modulo20 Test
36	Moving Inversion Test

C:	
37	Linear Seek Test
38	Random Seek Test
39	Funnel Seek Test
40	Surface Scan Test
41	SMART Status Test
42	SMART Short Self Test
43	SMART Extended Self Test
44	SMART Conveyance Self Test
HL-DT-ST DVD+-RW GSA-H31N	
45	(DVD-RW Drive) Read Write Test
46	(DVD-R Drive) Read Write Test
47	(CD-R Drive) Read Write Test
48	(DVD Drive) Linear Seek Test
49	(DVD Drive) Random Seek Test
50	(DVD Drive) Funnel Seek Test
51	(DVD Drive) Linear Read Compare Test
52	(DVD+R DL Drive) Read Write Test
53	(DVD+RW Drive) Read Write Test
54	(DVD+R Drive) Read Write Test
56	(CD-RW Drive) Read Write Test
57	CD-ROM Drive) Linear Seek Test
58	(CD-ROM Drive) Random Seek Test
59	(CD-ROM Drive) Funnel Seek Test
60	(CD-ROM Drive) Linear Read Compare Test
61	(CD-ROM Drive) CD Audio Test
Floppy disk drive	
62	Linear Seek Test
63	Random Seek Test
64	Funnel Seek Test
65	Surface Scan Test
PCDoctor® USB Test Key 2.0 USB Device	
66	Scan Test Port 1
67	Scan Test Port 2
68	Scan Test Port 3
69	Scan Test Port 4
70	Scan Test Port 5
71	Scan Test Port 6
Intel® Q965/Q963 Express Chipset Family	
72	Primary Surface Test
73	Fixed Transformation and Lighting Test
74	Transformation and Lighting Stress Test

Intel® Q965/Q963 Express Chipset Family	
75	Primary Surface Test
76	Fixed Transformation and Lighting Test
77	Transformation and Lighting Stress Test
Broadcom NetXtreme 57xx Gigabit Controller	
78	Network Link Test
79	TCP/IP Internal Loopback Test
80	Network External Loopback Test
HID Keyboard Device	
81	Keyboard Interactive Test
Dell™ USB Mouse	
82	Mouse Interactive Test
SoundMAX Integrated Digital HD Audio Driver	
83	Playback Mixer State Test
84	Sound Interactive Test
Intel® Q965/Q963 Express Chipset Family	
85	Audio Visual Interleave (AVI) Interactive Test
Dell ™ E157FP (Plug and Play Monitor)	
86	Monitor Interactive Test
Communications Port (COM1)	
87	External Register Test
88	External Loopback Test
89	Internal Register Test
90	Internal Control Signals Test
91	Internal Send and Receive Test
ECP Printer Port (LPT1)	
92	Internal Read and Write Test
93	External Read and Write Test
PCI Bus	
94	Configuration Test
PCDoctor® USB Test Key 2.0 USB Device	
95	USB Status Test
Dell™ USB Keyboard	
96	USB Status Test
Dell™ USB Mouse	
97	USB Status Test
Intel® Q963/Q965 PCI Express Root Port – 2991	
98	PCI Express Status Test
Microsoft UAA Bus Driver for High Definition Audio	
99	PCI Express Status Test
Intel® ICH8 Family PCI Express Root Port 1 - 283F	
100	PCI Express Status Test
Intel® ICH8 Family PCI Express Root Port 5 - 2847	
101	PCI Express Status Test
Broadcom NetXtreme 57xx Gigabit Controller	
102	PCI Express Status Test

SoundMAX Integrated Digital HD Audio Driver	
103	Rough Audio Test
Batch 5	
104	System Timer
105	BIOS Timer
106	IRQ Controller
107	DMA Channels
108	RAM Refresh
109	RTC Clock
110	CMOS RAM
111	Keyboard
112	PCI
113	USB Port
114	Video Memory
115	Video Pages
116	VGA Controller Registers
117	VGA Color-DAC Registers
118	VESA Full Video Memory Test
119	COM 1 Registers And Interrupts
120	COM 1 Internal Loopback
121	COM 1 FIFO Buffers (16550A)
122	LPT 1 Command And Data Port
123	SMBUS
Batch 4	
124	CPU 1 CPU Registers
125	CPU 1 CPU Arithmetics
126	CPU 1 CPU Logical Operations
127	CPU 1 CPU String Operations
128	CPU 1 CPU Misc Operations
129	CPU 1 CPU Interrupts/Exceptions
130	CPU 1 CPU Buffers/Cache
131	CPU 1 CoProc Registers
132	CPU 1 CoProc Commands
133	CPU 1 CoProc Arithmetics
134	CPU 1 CoProc Transcendental
135	CPU 1 CoProc Exceptions
136	CPU 1 MMX Test
137	CPU 2 CPU Registers
138	CPU 2 CPU Arithmetics
139	CPU 2 CPU Logical Operations
140	CPU 2 CPU String Operations
141	CPU 2 CPU Misc Operations
142	CPU 2 CPU Interrupts/Exceptions
143	CPU 2 CPU Buffers/Cache
144	CPU 2 CoProc Registers
145	CPU 2 CoProc Commands

146	CPU 2 CoProc Arithmetics
147	CPU 2 CoProc Transcendental
148	CPU 2 CoProc Exceptions
149	CPU 2 MMX Test
150	Base Fast Pattern
151	Base Fast Address
152	Base Medium Pattern
153	Base Medium Address
154	Base Heavy Pattern
155	Base Heavy Address
156	Base Bus Throughput
157	Extended Fast Pattern
158	Extended Fast Address
159	Extended Medium Pattern
160	Extended Medium Address
161	Extended Heavy Pattern
162	Extended Heavy Address
163	Extended Code Test
164	Extended Advanced Pattern
PCI post Card Test	
165	D1
166	D2
167	D3
168	D4
169	D5
170	D6
Power Supply Tests	
171	20/24
172	Motherboard
173	Hard drive
174	DVD drive
175	Floppy Drive

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United States
Environmental Protection
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